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JANUARY 1951

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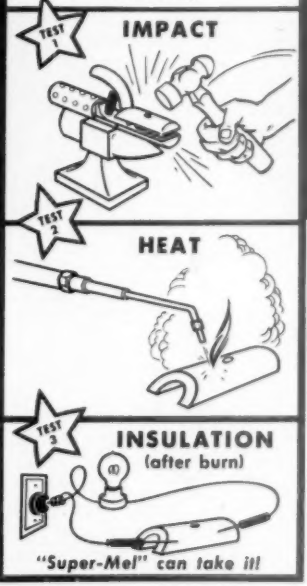

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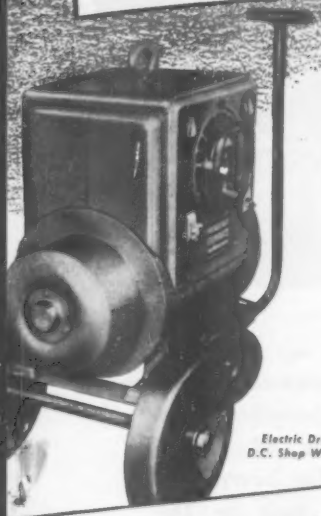

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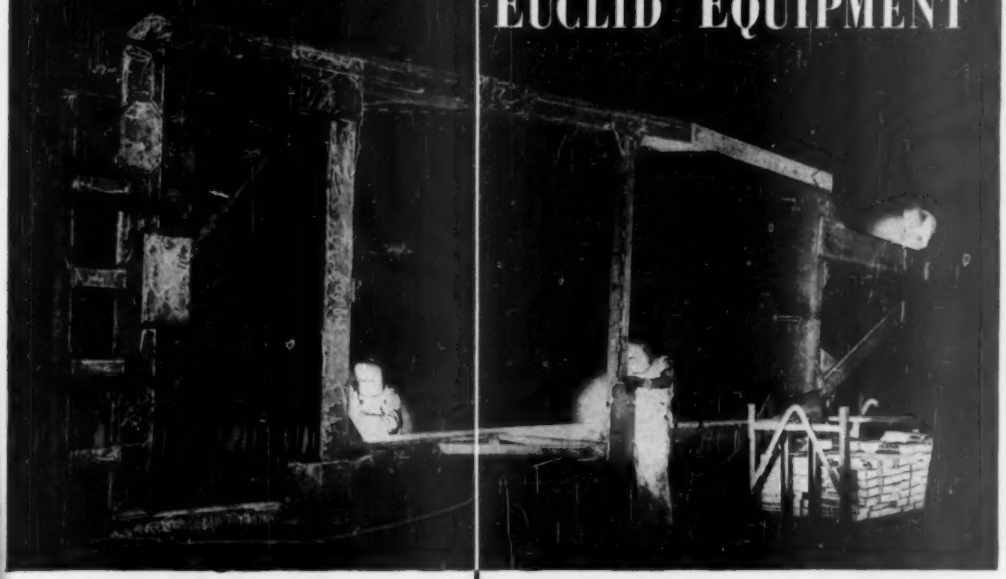

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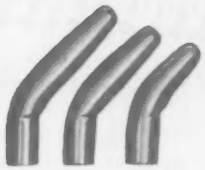

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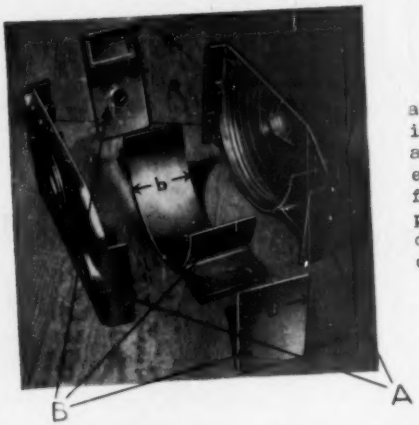

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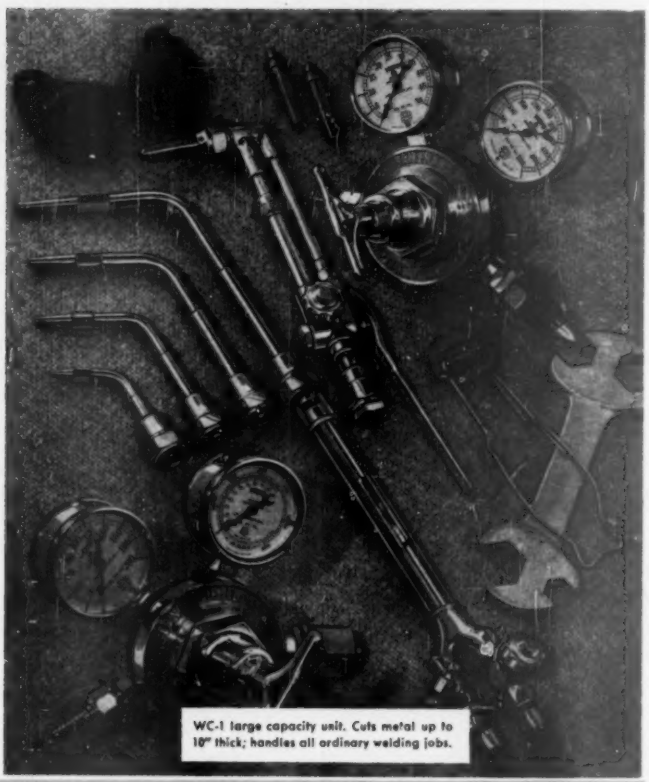

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The WELDING JOURNAL

volume 30 January, 1951 number 1

Aircomatic Welding of Copper-Base Alloys

A general investigation into the weldability of several copper-base alloys with the recently developed inert-gas-shielded metal-arc welding process. Mechanical properties of a few simple welded joints with a number of electrode-filler materials and several practical applications are included

by Harold Robinson and John H. Berryman

INTRODUCTION

SINCE the recent introduction of the Aircomatic Process for welding aluminum the range of metals for which this process has proved to be a "natural" has steadily increased. This has been particularly true of certain of the copper-base alloys which offer fewer problems with the Aircomatic Process than any of the other metals so far attempted. It seemed desirable therefore, at this stage of development, to present the results of a few weldability and joint property tests on several copper-base alloys welded with this process. A few successful industrial applications are also included.

Table 1 is a list of the materials used in this program with their corresponding A.S.T.M. specifications.

WELDING EQUIPMENT

All of the weld deposits described in this paper were made with a Model 2 Aircomatic manual unit and a standard welding Hornet generator. For those not already familiar with this process, it can be described briefly as inert-gas-shielded metal-arc welding. The gas-shielded arc is maintained between the workpiece and a consumable electrode which is transferred across the arc to the workpiece to become part of the joint. The combination of superheated transferred filler metal, and high heat intensity and energy concentration produces high deposition rates with good penetration resulting in unusually rapid welding speeds. The electrode is in the form of continuous wire which may vary up to 3/32 in. in diameter, depending on the work to be welded. The wire is fed semiautomatically through about 10 ft. of flexible cable to a hand gun. The gun terminates in a small nozzle which directs the gas, shielding the arc and wire as it emerges from the gun. The flexibility of the gun and projected metal transfer easily permit welding in all positions (downhand, vertical and overhead). A recent Aircomatic model is shown in Fig. 1 in which all of the essential features are shown; Fig. 2 shows the gun in use welding vertically upward.

Welding with this process is always done with d.-c. reverse polarity. Any standard welding generator may be used which exhibits a drooping v. amp. curve and a minimum open-circuit voltage of about 50 v. A more complete description of the process can be obtained from the article in the June 1950 issue of THE WELDING JOURNAL, "The Aircomatic Welding Process" by Muller, Gibson and Roper.

WELDABILITY

The bulk of this paper is devoted to deposits made

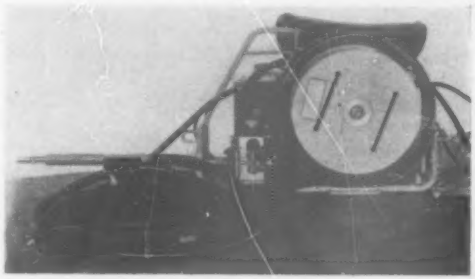

Fig. 1 The aircomatic gun—model 3

Harold Robinson, Research Laboratory, **John H. Berryman,** Technical Sales, Air Reduction Co., Inc., Murray Hill, N. J., and New York, N. Y., respectively.

Paper presented at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

Fig. 2 The aircomatic gun in operation—vertical fillet

with aluminum-bronze and silicon-bronze electrode wire. Welds made with these wires under proper conditions are bright, clean and smooth with good contour and excellent appearance. These welds are dense, fine grained and significantly free of macro or micro porosity, easily meeting all X-ray quality requirements of the unfired pressure-vessel codes. Argon is the preferred shielding gas for most copper alloys. With proper welding conditions the arc is extremely smooth and stable under a wide range of welding currents. Metal transfer is of the drop type with the drops decreasing in size but increasing in frequency as the current (or current density) is increased for a given wire size. For instance, with $^1/_{16}$-in. diameter wire at 50 amp., the transfer is discrete large globules simply falling under the force of gravity and unsuitable for any practical application. At 175–200 amp. the drops are small and numerous and the transfer is in the form of a projected spray of metal suitable for welding in all positions. (Where the current is too high for the workpiece, the projected type transfer can be obtained with smaller diameter wires at correspondingly lower currents.) Currents as high as 500 amp. have been used on $^1/_{16}$-in. diameter wire, but the next size wire, $^3/_{32}$-in. diameter, would be preferred for down-hand welding at 350 amp. and over.

With proper welding conditions there will be practically no spatter loss. Spatter is believed to be caused by short circuiting the drops at the end of the electrode with the workpiece. At low currents the drops are fairly large and will short circuit and spatter at a comparatively long arc length. As the current increases, the drops decrease in size and correspondingly shorter arc

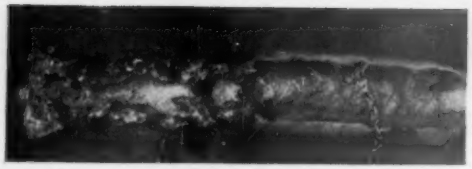

Fig. 3 Aluminum-bronze deposit on steel plate with and without scale

lengths can be used without short circuiting and spatter. An exception to this is welding on copper alloys containing zinc. The vaporization of the volatile zinc in the base plate under the arc requires special care to keep spatter loss at a minimum. Satisfactory deposits can be made on the copper-zinc alloys by welding backhand and maintaining the arc on deposited metal as much as possible. The radiated heat of the arc will "wash" the adjacent base metal permitting very satisfactory wetting with the deposit. Lower than normal currents should be used. After the first layer deposit has been made, the current and wire feed can be raised and welding will proceed in the normal manner, full advantage being taken of the high deposition rate and low spatter loss possible with the process.

Though sound welds can be made with helium, the large increase in spatter and reduced visibility make this gas less desirable for the copper-base alloys. An exception is made when welding on pure copper plate. The higher currents required for copper reduce spatter appreciably. In addition, the helium arc produces higher heat, deeper penetration and faster welding speeds, making this gas sometimes more preferable than argon.

It is good practice to remove heavy oxide and scale whenever possible to improve the wetting action, espe-

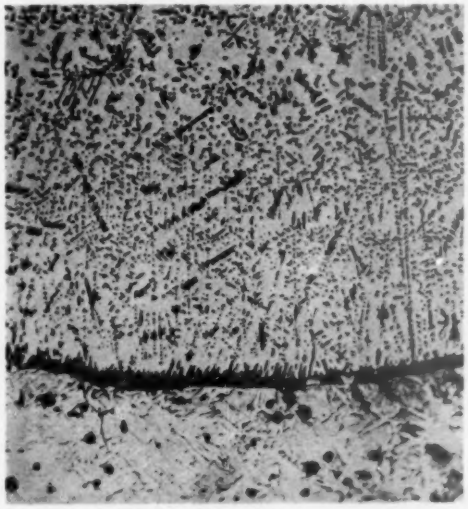

Fig. 4 Photomicrograph of aluminum-bronze deposit on steel plate. $FeCl_3$ Etch. 250 ×

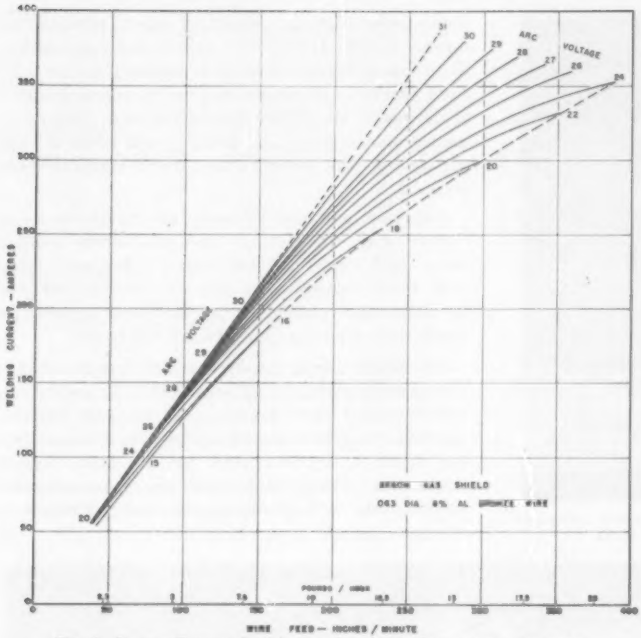

Fig. 5 Burn-off curve for $^{1}/_{16}$-in. aluminum-bronze wire in argon

cially for overlaying where penetration should be kept low. An extreme example is shown in Fig. 3 where half of a hot-rolled steel plate was descaled and a single aluminum-bronze stringer bead deposited. The deposit on the descaled portion was bright and smooth with perfect wetting, while the scaled portion showed poor fusion, no wetting and produced a very erratic arc. Equally satisfactory deposits may be made either backhand or forehand. Forehand welds, particularly in aluminum bronze, are bright and golden in appearance while backhand welds are covered with an easily removable smut. Since there is no wire coating or flux, special welding techniques, chipping or cleaning, are not required to avoid slag entrapment.

Figure 5 shows a series of burn-off curves for a $^{1}/_{16}$-in. diameter 8% aluminum-bronze electrode wire in argon. The lower envelope represents zero arc length while the upper envelope represents an extreme $^{3}/_{8}$-in. arc length. In general, the shorter arc lengths will produce a narrower, more convex bead with higher penetration than long arc lengths. In welding fillets or butt joints where penetration is desirable, one would weld in the lower third of this envelope. For overlaying where a flat deposit with little penetration or plate dilution is desired, welding would be done in the middle third portion of the envelope for at least the first layer. The envelope broadens out appreciably above 200 amp. In certain overlay applications a skilled operator can take good advantage of this phenomenon for producing smooth flat overlays by cutting back on the wire feed to produce a long soft arc with a minimum deposition rate similar to the way an oxyacetylene operator will manipulate his torch for brazing. Note that it is no problem to deposit metal at a rate of about 15 lb. an hour with suitable heavy-duty equipment if the workpiece is heavy enough to take the required current though a $^{3}/_{32}$-in. diameter electrode wire would be preferred for this deposition rate.

Photographs of a few typical joints are shown in Figs. 6 to 8. Figure 6 is a horizontal fillet in $^{3}/_{8}$-in. aluminum bronze, test plate 23. Note the contour of the fillet and root penetration. Figure 7 is a butt weld in a $1^{1}/_{2}$-in. thick manganese-bronze propeller casting showing good fusion, perfect wetting action, and low reinforcement, test plate 15. Figure 8 shows an overlay on a $^{3}/_{8}$-in. steel plate. The flexibility of the process is shown in the contrast of the full root penetration of Fig. 6 with the minimum penetration of this overlay. Figure 8 also shows the smooth, spatter-free surface of the weld bead and the soundness of the machined deposit.

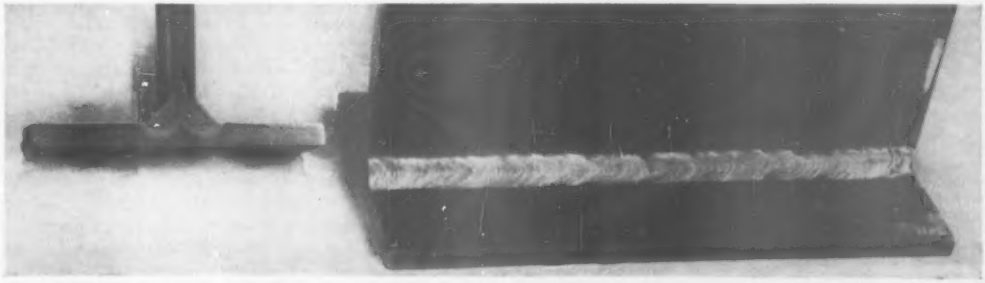

Fig. 6 Horizontal fillet in $^{3}/_{8}$-in. aluminum-bronze test plate 23

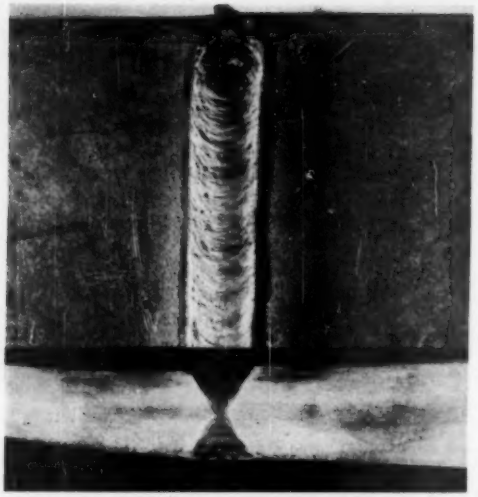

Fig. 7 Butt weld in 1½-in. manganese-bronze test plate 15, aluminum-bronze filler (EcuAl-A)

bronze, silicon bronze, deoxidized copper, phosphor tin bronze, leaded phosphor tin bronze and cupro-nickel. The brass or manganese-bronze compositions are difficult to use for electrode material due to the vaporization of the zinc in the intense heat of the arc. Alloys containing zinc, even as low as ½%, will result in high spatter loss, poor wetting action and fusion to the base material.

Aluminum and silicon bronzes are completely satisfactory with this process over the whole welding range and under all conditions. Deposits made with these materials are free of porosity and can be unqualifiedly recommended for those applications where their particular analyses are indicated.

Deoxidized copper produces sound deposits at currents which are about double that normally used for the aluminum and silicon bronzes. At the lower currents, the chilling action of the copper-base material will usually result in deposits which are somewhat porous. Any method which will decrease the cooling rate, such as preheating, or high welding currents, will reduce or eliminate porosity.

Fig. 8 One-, two- and three-pass aluminum-bronze overlay on ¼-in. steel plate. Note smooth, spatter-free deposit and low penetration

ELECTRODE WIRE MATERIALS

Satisfactory deposits have been made with electrode wire of the following copper-base alloys: aluminum

The phosphor bronzes also tend toward pinhole porosity when welded without preheat. In certain applications for bearing surfaces, pinhole porosity has not been objectionable. Unqualified recommendation

Table 1—Nominal Chemical Composition of Materials—Copper Remainder

			Composition, %						
Alloy	*Form*	*A.S.T.M. Specification*	*Al*	*Fe*	*Mn*	*Si*	*Sn*	*Pb*	*Ni*
Aluminum bronze	Plate	B169–49, Alloy A	5.0	0.50 max.	...	...	...	...	...
Aluminum bronze	Plate	B169–49, Alloy D	6–8	1.5–3	...	...	...	...	...
Aluminum bronze	Plate	B171–49	9.5	2.5	1.0	...	...	...	5.0
Aluminum bronze	Wire	B169–49, Alloy A*	5.0	0.50 max.	...	...	...	...	...
Aluminum bronze	Wire	B169–49, Alloy C*	8.0	0.50 max.	...	...	...	...	...
Aluminum bronze	Wire	B225–48T, ECuAl-A*	9.5	0.75	...	...	...	...	...
Silicon bronze	Plate	B96–49, Alloy A	...	...	1.1	3.1	...	...	...
Silicon bronze	Wire	B225–48T, ECuSi*	...	...	1.1	3.1	...	...	...
Manganese bronze	Casting	B99–49, Alloy A B147–49, Alloy 8A Navy 49B3F	0.5–1.5	0.4–2.0	1.5 max.	Cu, 55–60, Zn Bal.			
Leaded tin bronze	Casting	...	...	...	...	...	7.2	5.6	1.3
Deoxidized copper	Plate	B152–49T, Type DHP	...	...	...	...	...	...	...
Deoxidized copper	Wire	...	...	...	0.20	0.20	0.75	...	...
Phosphor bronze, A	Wire	B159–49T, Alloy A	...	...	...	...	4.0	...	...
Phosphor bronze, C	Wire	B159–49T, Alloy C	...	...	...	...	8.0	...	...
Leaded phosphor bronze, B1	Wire	B139–49T, Alloy B1*	...	...	...	...	4.0	1.0	...
Leaded phosphor bronze	Wire	...	...	...	...	...	4.0	4.0	...
Electrolytic tough pitch copper	Plate	B152–49T, Type ETP	...	...	...	...	...	...	...

* Wire has same composition as material of this specification.

Table 2—Recovery of Alloying Elements in Aircomatic Welding Copper-Base Alloys

Alloy		Pass	Alloying Elements, %						
			Al	Fe	Mn	Si	Sn	Pb	Zn
Aluminum bronze	Wire	...	9.19	0.10	...	...	...	...	...
	Deposit	3	8.67	1.68*	...	...	...	...	...
Aluminum bronze	Wire	...	7.25	1.39	0.93	...	...	...	...
	Deposit	3	7.19	2.39*	0.94	...	...	...	...
Aluminum bronze	Wire	...	8.95	...	...	...	...	...	0.56
	Deposit	4	8.33	...	...	...	...	...	0.56
Silicon bronze	Wire	...	...	0.15	1.10	2.84	...	...	...
	Deposit	3	...	0.56*	1.05	2.71	...	...	...
Phosphor bronze, A	Wire	...	...	0.01	...	...	4.56	...	...
	Deposit	3	...	1.47*	...	...	4.60	...	...
Phosphor bronze, leaded	Wire	...	...	0.05	...	...	5.24	3.66	...
	Deposit	6	...	0.04	...	...	4.97	3.57	...

* High Fe due to plate-metal dilution.

of this material cannot be made at the present time. The leaded phosphor-bronzes deposit similarly to the straight phosphor-bronze types. The lead remains finely divided and evenly dispersed as is shown in Fig. 28.

Unfortunately, insufficient work has been done on the cupro-nickel alloys to make a fair evaluation at this date. The results thus far are encouraging.

TRANSFER EFFICIENCY

When welding current and arc length (voltage) are properly adjusted, spatter loss is insignificant. Aircomatic welded test pads made on a carefully weighed plate with $^1/_{16}$-in. diameter aluminum-bronze wire showed an over-all deposition efficiency of 99%. The loss due to end-clippings was about $^1/_2$% with the balance apparently due to spatter and vaporization of filler metal. This test was done with 30 cfh. of argon at 245 amp. 26$^1/_2$ v., deposition rate: 8$^1/_2$ lb. per hour.

In comparison a similar pad was made with $^3/_{16}$-in. diameter coated aluminum-bronze electrodes of the same analysis. Here the over-all deposition efficiency was only 67%. The stubb-end loss was about 8$^1/_2$%, the balance being lost through coating, spatter and evaporation. This pad was made at 225 amp. and 27$^1/_2$ v., deposition rate: 7 lb. per hour. Stubb-ends, coating and spatter loss represent undeposited material which costs money.

One of the features of the Aircomatic Process is the efficiency of the inert-gas shielding. There is no significant loss of even the more readily oxidizable elements. Extra alloying elements do not have to be added to the wire or coating to make up for any such loss. Several pads from different filler wires were made on a steel plate and analyzed for recovery of elements. These results are shown in Table 2.

RECOMMENDED SETTINGS

Suggested welding conditions for various plate thicknesses are given in Table 3. These data are intended merely as a guide and are not represented as being the optimum settings for all conditions. It is realized that techniques and practices peculiar to certain jobs will require their own modifications.

Table 3—Conditions for Aircomatic Welding Aluminum Bronze and Steel Plate with Aluminum-Bronze Electrode Wire

Plate thickness, in.	Position	Wire size, in.	Current
$^1/_8$	F, H, OH, VD	$^3/_{64}$	110–120
$^3/_{16}$	F, H, OH, VD	$^3/_{64}$	110–180
$^1/_4$	OH, V	$^3/_{64}$	110–140
$^1/_4$	F, VD, H, OH	$^3/_{64}$	170–190
$^1/_4$	F, H	$^1/_{16}$	190–310
$^3/_8$	F, H	$^1/_{16}$	280–350
$^3/_8$	V, OH	$^3/_{64}$	110–200
$^1/_2$	F, H	$^1/_{16}$	280–350
$^1/_2$	V, OH	$^3/_{64}$	140–210

Silicon-bronze wire requires about 10–30% less current due to high fluidity of deposited metal.

Cold copper plate, due to high heat conductivity, requires about 100% more current with a correspondingly larger wire size.

F = flat; H = horizontal; OH = overhead; V = vertical-up and VD = vertical-down.

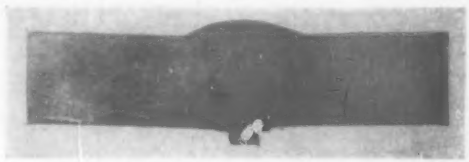

Fig. 9 Butt-weld in $^1/_2$-in. aluminum-bronze test plate 8, aluminum-bronze filler

Fig. 10 Butt-weld in $^1/_2$-in. aluminum-bronze test plate 10, aluminum-bronze filler

Fig. 11 Butt-weld in $^1/_2$-in. silicon-bronze test plate 12, silicon-bronze filler

Table 4 Welding Conditions for Test Plates of Bronze-Welded Joints

TEST PLATE NO.	PLATE SPECIFICATION	ELECTRODE	JOINT	PASSES	CURRENT	VOLTAGE	SHIELDING GAS	TOTAL WELDING SPEED
1.	3/8" B 103, ALLOY D Al. BRONZE	1/16" B 103, ALLOY D	90° 3/8 ROOT CHIPPED	3	275	27	ARGON-35 C.F.H.	5.15 IN./MIN.
2.	3/8" B 103, ALLOY D Al. BRONZE	1/16" ECuAl-A		3	285	27	ARGON-35 C.F.H.	5.53 IN./MIN.
3.	3/8" B 103, ALLOY D Al. BRONZE	1/16" B 103, ALLOY C 8% Al. BRONZE		3	290	27	ARGON-35 C.F.H.	5.55 IN./MIN.
4.	3/8" B 103, ALLOY A 5% Al. BRONZE	1/16" B 103, ALLOY A		3	290	27	ARGON-35 C.F.H.	5.45 IN./MIN.
5.	3/8" B 171 - 49 Al. BRONZE	1/16" ECuAl-A		3	290	27	ARGON-35 C.F.H.	6.15 IN./MIN.
6.	3/8" B 96, ALLOY A Si BRONZE	1/16" ECuSi		3	285	28	ARGON-35 C.F.H.	4.50 IN./MIN.
7.	1/2" B 103, ALLOY D Al. BRONZE	1/16" B 103, ALLOY D	60° 1/2	3	280	28	ARGON-35 C.F.H.	3.89 IN./MIN.
8.	1/2" B 103, ALLOY D Al. BRONZE	1/16" ECuAl-A		3	320	29	ARGON-35 C.F.H.	4.62 IN./MIN.
9.	1/2" B 103, ALLOY D Al. BRONZE	1/16" B 103, ALLOY C		3	300	29	ARGON-35 C.F.H.	4.11 IN./MIN.
10.	1/2" B 103, ALLOY A Al. BRONZE	1/16" B 103, ALLOY A		3	340	27 1/2	ARGON-35 C.F.H.	4.33 IN./MIN.
11.	1/2" B 171 - 49 Al. BRONZE	1/16" ECuAl-A		3	320	28 1/2	ARGON-35 C.F.H.	5.0 IN./MIN.
12.	1/2" B 96, ALLOY A Si BRONZE	1/16" ECuSi		3	290	27 1/2	ARGON-35 C.F.H.	4.9 IN./MIN.
13.	3/4" B 96, ALLOY A Si BRONZE	1/16" ECuSi	60° 3/4 1/2	8	280	28	ARGON-35 C.F.H.	
14.	1 1/2" B 147, ALLOY 9A Mn BRONZE	1/16" ECuAl-A	45° 1 1/2 1/2	12	310-320	27-29	ARGON-35 C.F.H.	
15.	1 1/2" B 147, ALLOY 9A Mn BRONZE	1/16" ECuAl-A	60° 1 1/2 1/8 1/16 ROOT CHIPPED 60°	9	280-300	27-28	ARGON-35 C.F.H.	
16.	1 1/2" B 147, ALLOY 9A Mn BRONZE	1/16" B 103, ALLOY C Al. BRONZE	45° 1 1/2 1/2	12	300	27-29	ARGON-35 C.F.H.	
17.	1 1/2" B 147, ALLOY 9A Mn BRONZE	1/16" B 103, ALLOY C Al. BRONZE	60° 1 1/2 1/8 1/16 ROOT CHIPPED 60°	9	350-360	28-29	ARGON-35 C.F.H.	
18.	3/8 MILD STEEL	1/16" ECuAl-A	75° 3/8 1/16	3	290	27-28	ARGON-35 C.F.H.	
19.	3/4" MILD STEEL	1/16" ECuAl-A	60° 3/4 1/2	7	280	27-29	ARGON-35 C.F.H.	
20.	3/4" MILD STEEL	1/16" B 103, ALLOY C		7	275	27-29	ARGON-35 C.F.H.	
21.	1/4" B 152, DHP DEOXIDIZED COPPER	3/32 DEOXIDIZED COPPER	60° 3/8 1/4	1	430		ARGON-45 C.F.H.	17.0 IN./MIN.
22.	1/8" B 103, DHP DEOXIDIZED COPPER	1/16" ECuSi	60° 1/8 1/4	2	350	28	ARGON-45 C.F.H.	
23.	3/8" B 103, ALLOY D	ECuAl-A		1	335	28	ARGON-35 C.F.H.	15.0 IN./MIN.

MECHANICAL PROPERTY TESTS

Butt welds were made in 3/8-, 1/2- and 3/4-in. bronze and steel plates and a 1 1/2-in. manganese-bronze casting for determining joint properties. The welding conditions and joint descriptions are given in Table 4. Argon was used for the shielding gas in all cases. The joints were welded downhand with the 1/16-in. diameter wire and without preheat except for the residual heat remaining from previous passes. Figures 9 to 11 are macrosections of 1/2-in. bronze plates and Figs. 12 and 13 are butt welds in 1/4-in. copper with deoxidized copper and silicon-bronze fillers.

The results of mechanical tests are given in Table 5. In all cases results are the average of at least three specimens except the impact results which are given for each specimen. Transverse tensile specimens were machined flush to remove all reinforcement. The keyhole of the impact specimens was located in the center of the joint deposit perpendicular to the axis of the weld. All welds were free of porosity on X-ray examination. The properties of the welded joints made with the proper filler metal compare favorably with minimum base-metal properties. The results listed in Table 5 were obtained from the specific joints described in Table 4 and are not represented as being either average or minimum values obtainable with this process. Minimum properties of the various copper-alloy base materials are shown in Table 6.

Table 5—Mechanical Properties of Bronze-Welded Joints

Test Plate No.	*Plate*	*Wire*	*Specimen*	*Ultimate Tensile strength, psi.*	*Elongation, %, 2 in.*	*Fracture*	*Bend*	*Impact, ft.-lb. 78° F.*	*−40° F.*	*−320° F.*
1	3/8-In. B169, Alloy D aluminum bronze	1/16-In. B169, Alloy D aluminum bronze	Transverse tensile	75,980	34 1/2	In weld	...	...	...	...
	3/8-In. B169, Alloy D aluminum bronze	1/16-In. B169, Alloy D aluminum bronze	Guided bend	...	...	...	180°	...	...	...
7	1/2-In. B169, Alloy D aluminum bronze	1/16-In. B169, Alloy D aluminum bronze	Keyhole charpy	...	...	...	...	23 21 23.5	23 20.5 24	15 26 16
2	3/8-In. B169, Alloy D aluminum bronze	1/16-In. ECuAl-A aluminum bronze	Transverse tensile	77,325	39	Bond line	...	...	...	...
	3/8-In. B169, Alloy D aluminum bronze	1/16-In. ECuAl-A aluminum bronze	Guided bend	...	...	...	180°	...	...	...
8	1/2-In. B169, Alloy D aluminum bronze	1/16-In. ECuAl-A aluminum bronze	Keyhole charpy	...	...	...	...	37.5 42 38	40 35 32	32 33 33
3	3/8-In. B169, Alloy D aluminum bronze	1/16-In. B169, Alloy C aluminum bronze	Transverse tensile	63,500	21	In weld	...	...	...	...
	3/8-In. B169, Alloy D aluminum bronze	1/16-In. B169, Alloy C aluminum bronze	Guided bend	...	...	...	180°	...	...	...
9	1/2-In. B169, Alloy D aluminum bronze	1/16-In. B169, Alloy C aluminum bronze	Keyhole charpy	...	...	...	...	45 62* 64*	46 47 71*	45 34 43
4	3/8-In. B169, Alloy A aluminum bronze	1/16-In. B169, Alloy A aluminum bronze	Transverse tensile	43,250	24	In weld	...	...	...	...
	3/8-In. B169, Alloy A aluminum bronze	1/16-In. B169, Alloy A aluminum bronze	Guided bend	...	...	..	180°	...	...	...
10	1/2-In. B169, Alloy A aluminum bronze	1/16-In. B169, Alloy A aluminum bronze	Keyhole charpy	...	...	...	...	28 27* 35*	27 39* 30*	33 32 28.5
5	3/8-In. B171-49 aluminum bronze	1/16-In. ECuAl-A aluminum bronze	Transverse tensile	96,300	28	In weld	...	...	...	...
	3/8-In. B171-49 aluminum bronze	1/16-In. ECuAl-A aluminum bronze	Guided bend	...	...	...	35*	...	...	...
11	1/2-In. B171-49 aluminum bronze	1/16-In. ECuAl-A aluminum bronze	Keyhole charpy	...	...	...	...	19 19.5 18	12 18.5 19	16.3 15 15.5
6	3/8-In. B96, Alloy A silicon bronze	1/16-In. ECuSi silicon bronze	Transverse tensile	52,700	45	In weld	...	...	...	...
	3/8-In. B96, Alloy A aluminum bronze	1/16-In. ECuSi silicon bronze	Guided bend	...	...	...	180°	...	...	...
12	1/2-In. B96, Alloy A aluminum bronze	1/16-In. ECuSi silicon bronze	Keyhole charpy	...	...	...	...	33 38	36 32	36 42
13	3/8-In. B96, Alloy A aluminum bronze	1/16-In. ECuSi silicon bronze	All-weld-metal (0.505)	52,500	34	...	...	48*	45*	37
14	1 1/2-In. B147, Alloy 8A manganese bronze	1/16-In. ECuAl-A aluminum bronze	All-weld-metal (0.505)	81,200 (top), 78,450 (bottom)	31 21	...	...	...	...	...
15	1 1/2-In. B147, Alloy 8A manganese bronze	1/16-In. ECuAl-A aluminum bronze	Transverse tensile	62,200	9 1/2	Bond line	...	...	...	...
16	1 1/2-In. B147, Alloy 8A manganese bronze	B169, Alloy C aluminum bronze	All-weld-metal (0.505)	46,375 (top), 26,750 (bottom)	36 12 1/2	...	...	...	...	...
17	1 1/2-In. B147, Alloy 8A manganese bronze	B169, Alloy C aluminum bronze	Transverse tensile	45,920	...	...	...	...	...	...
18	3/8-In. mild steel	1/16-In. ECuAl-A aluminum bronze	Transverse tensile	66,350	...	Base metal	...	...	...	...
	3/8-In. mild steel	1/16-In. ECuAl-A aluminum bronze	Guided bend	...	...	...	180°	...	...	...
19	1/2-In. mild steel	1/16-In. ECuAl-A aluminum bronze	All-weld-metal (0.505)	104,500	20	...	...	...	...	...
20	3/4-In. mild steel	B169, Alloy C aluminum bronze	All-weld-metal (0.505)	70,750	29 1/2	...	...	...	...	...
21	1/4-In. B152, DHP deoxidized copper	1/16-In. deoxidized copper	Transverse tensile	30,050	28	Bond line	...	...	...	...
	1/4-In. B152, DHP deoxidized copper	5/32-In. dioxidized copper	Free bend	...	23–42	...	180°	...	...	...
	1/4-In. B152, DHP deoxidized copper	1/16-In. ECuSi	Transverse tensile	29,850	37	Bond line	...	...	...	...
	1/4-In. B152, DHP deoxidized copper	1/16-In. ECuSi	Free bend	...	23	...	180°	...	...	...
	1/4-In. B150-ETP electrode T. P. Cu	5/32-In. deoxidized copper	Transverse tensile	26,450	25	Bond line	...	...	...	...
	1/4-In. B159-ETP electrode T. P. Cu	5/32-In. dioxidized copper	Free bend	...	22–40	...	180°	...	...	...

* Specimen did not fracture.

Table 6—Minimum Mechanical Properties of Annealed Copper—Alloy Plate Material

Alloy	Specification	Tensile strength, psi.	Elongation, %, 2 in.	Keyhole Charpy, ° F.*		
				78	−40	−320
Aluminum bronze	B169-49, Alloy A	45,000	40	100	110	128
Aluminum bronze	B169-49, Alloy D	72,000	35	45	50	44
Aluminum bronze	B171-49	90,000	10	7.5	7.5	6
Silicon bronze	B96-49, Alloy A	50–67,000	40	103	112	125
Manganese bronze	B147-49, Alloy 8A	65,000	20	..	..	..
Deoxidized copper	B152-49, DHP	30,000	..	..	..	..

* Laboratory tests, average of 3 specimens.

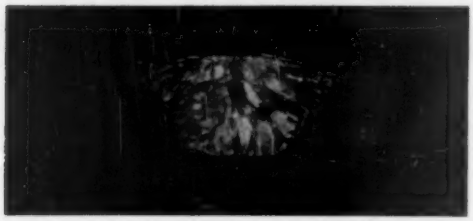

Fig. 12 Butt-weld in 1/4-in. deoxidized-copper test plate 21, deoxidized-copper filler

Fig. 13 Butt-weld in 1/4-in. deoxidized-copper test plate 22, silicon-bronze filler

Fig. 14 All-weld-metal tensile specimen, aluminum-bronze filler, test plate 19

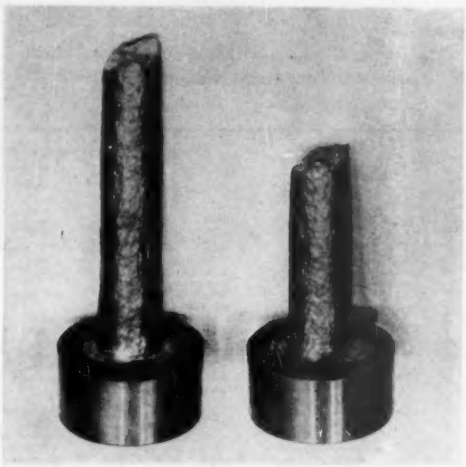

Fig. 15 All-weld-metal tensile specimen, silicon-bronze filler, test plate 13

Photographs of tested specimens are shown in Figs. 14 to 18. Figure 14 is an all-weld-metal tensile specimen of high-strength aluminum bronze deposited in 3/4-in. mild steel test plate 19. The fracture shows a dense, fine grain structure with good ductility. Figure 15 is an all-weld-metal tensile specimen from the very ductile silicon-bronze test plate 13. The strained surface is characteristic of ductile, single-phase, face-centered alloys. Figure 16 shows guided root and face bends and reduced section tensile specimens in mild steel test

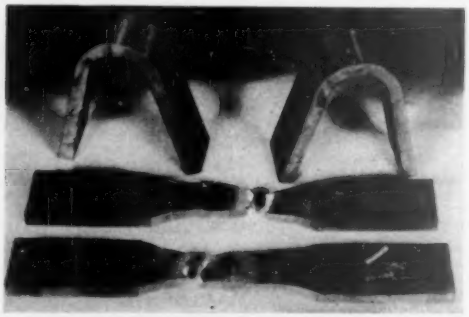

Fig. 16 Guided bend (face and root) and reduced-section tensile specimens from mild-steel test plate 18 with aluminum-bronze filler

Fig. 17 Reduced-section tensile specimens in 1½ in. manganese-bronze test plate 15, aluminum-bronze filler

plate 18 with aluminum-bronze ECuAl-A filler. Note that failure has taken place in the base metal beyond the heat-effected zone. The reduced-section transverse tensile specimen in manganese-bronze test plate 15 is shown in Fig. 17. The strength of the base metal in the heat-affected zone is just about equal to the deposited metal (after dilution). Note the difference in grain size between the weld metal and base-metal fractures.

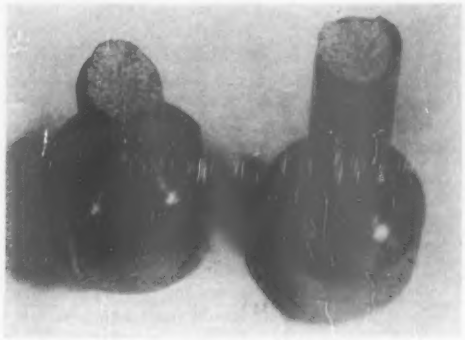

Fig. 18 (A) Manganese-bronze test plate 14 with ECuAl-A filler, all-weld metal

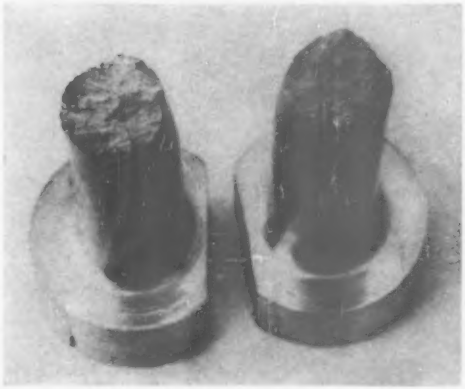

Fig. 18 (B) Magnesium-bronze test plate 16 with B169, Alloy C filler, all-weld metal

A comparison of the all-weld-metal tensile specimens from the manganese-bronze test plates 14 and 16, respectively, is interesting. Test plate 14, Fig. 18 (*A*), was welded with an ECuAl-A (9.5% Al, 0.75% Fe) filler wire. The iron content of this alloy resulted in a high-strength, fine-grained deposit. Test plate 16, welded with B169, Alloy C (8% Al) was appreciably weaker and exhibited a coarse grain fracture, Fig. 18 (*B*). In both of these joints, it was possible to remove all-weld-metal specimens from the upper and lower section of the deposit. In all cases, the lower specimens, due to increased dilution from the copper-zinc base material, were appreciably lower in strength than the upper specimens. If the base material had been steel, the effect of dilution would have had the opposite effect.

HARDNESS TRAVERSE

Hardness traverses were made on several of the bronze butt welds and are shown in Fig. 19. The effect of plate-metal dilution is shown by comparing the deposited hardness of the ECuAl-A deposits with different base materials. This effect, of course, could be influenced to a large degree by the amount of penetration as effected by welding technique and current.

METALLOGRAPHY

Photomicrographs were taken across the bond line to illustrate the change in structures from base metal to deposited weld metal. The metallurgy of aluminum bronze containing over 9% aluminum is a complex subject. The metallographic structures and mechanical properties of these alloys can be changed appreciably by making small alloying additions, as well as by the effect of heating or cooling. Both of these influences become of major importance in welding due to plate-metal dilution and the heating and cooling effect from multipass deposits. Figure 4 shows the interface of an aluminum-bronze deposit on mild steel. The diffusion of iron into the deposit is pronounced. Fortunately, iron has a grain refining and strengthening effect on aluminum bronze unless it becomes excessive. It is possible to use straight aluminum bronze for joining steel and obtain superior deposits therefrom than the electrode wire analysis would indicate.

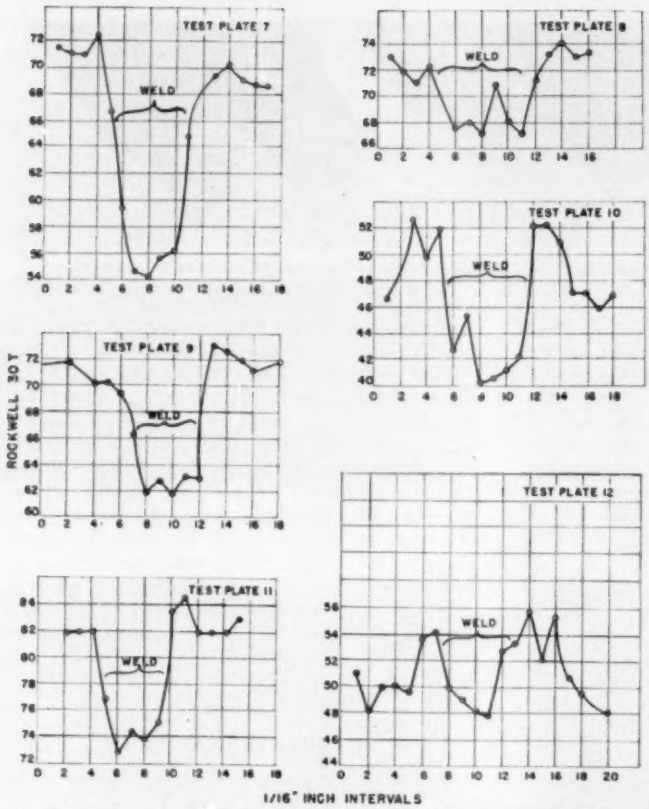

Fig. 19 Hardness traverse across butt-welds in test plates 7 (B169, Alloy D plate and wire), 8 (B169, Alloy D plate and ECuAl-A wire), 9 (B169, Alloy D plate and Alloy C wire), 10 (B169, Alloy A plate and wire), 11 (B171-49 plate and ECuAl-A wire), 12 (B96, Alloy A plate and wire)

Figure 20 is a section through the weld of test plate 7. Both plate and wire are the same composition, complete solid solution type (6–8% Al, 1.5–3% Fe). The base metal and deposit are single phase materials showing perfect grain boundary continuity across the interface, the base-metal grains acting as nuclei for solidification and grain growth of the deposited metal. The base metal shows the twinned structure characteristic of work-hardened and annealed alpha-phase alloys.

Figure 21, the photomicrograph of test plate 8, shows an entirely different structure. The base-plate material is the same as in the previous photomicrograph (6–8% Al, 1.5–3% Fe) but the deposited metal is of somewhat higher alloy content (9.5% Al, 0.75% Fe). The higher percentage of aluminum has shifted the composition to all beta phase at around 1890° F. which on cooling precipitates small alpha grains (light) along crystallographic planes. The dark matrix is the result of the remaining beta phase transforming to alpha and alpha plus delta eutectoid. This fine-grained Widmanstätten structure results in a maximum combination of strength and ductility. The high deposition and cooling rate and lack of required preheat with the Aircomatic Process make it relatively simple to deposit these desired fine-grained structures normally associated with chilled cast aluminum bronze.

The photomicrograph of plate 9, Fig. 22, is again the same base-plate material (6–8% Al, 1.5–3% Fe) with an 8% aluminum-bronze filler wire. The aluminum content of both the plate and wire produce a single-phase alloy similar to plate 7, showing the same grain continuity at the interface.

Test plate 10, Fig. 23, is a single-phase alloy (5% Al)

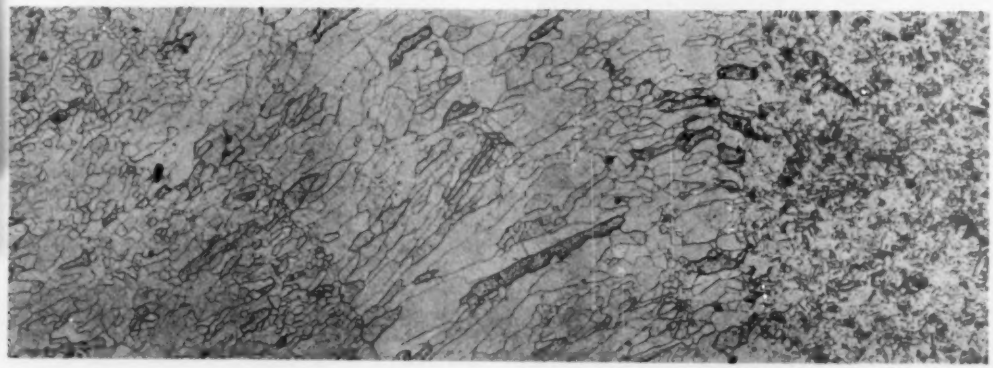

Fig. 20. Photomicrograph of weld interface aluminum-bronze test plate 7, (B169, Alloy D plate and wire). $FeCl_3$ Etch 100 ×

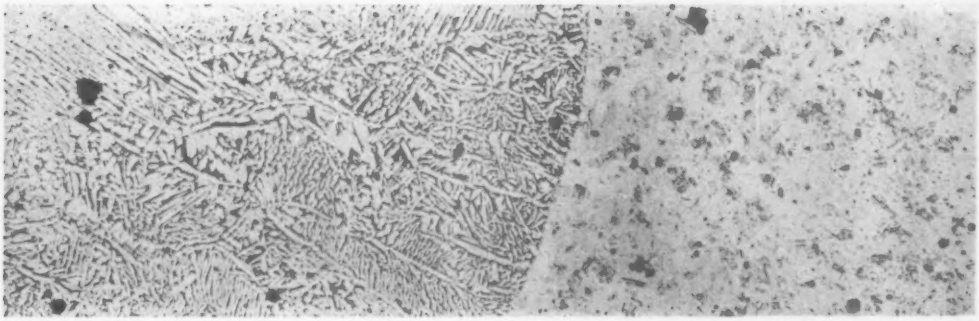

Fig. 21 Photomicrograph of weld interface aluminum-bronze test plate 8, (B169, Alloy D plate and ECu Al-1 wire). $FeCl_3$ Etch. 100 ×

with a deposited metal of the same composition. The structure is similar to that obtained in plate 7 and 9, though the strength of this joint is lower due to the lower alloy content.

Test plate 11 is a high-strength duplex structure aluminum-bronze alloy (9.5% Al, 2.5% Fe, 1.0% Mn, 5.0% Ni) welded with a two-phase filler wire (9.5% Al, 0.75% Fe), Fig. 24. The deposited metal being similar in structure to the base metal, the interface

Fig. 22. Photomicrograph of weld interface aluminum-bronze test plate 9, (B169, Alloy D plate and Alloy C wire). $FeCl_3$ Etch. 100 ×

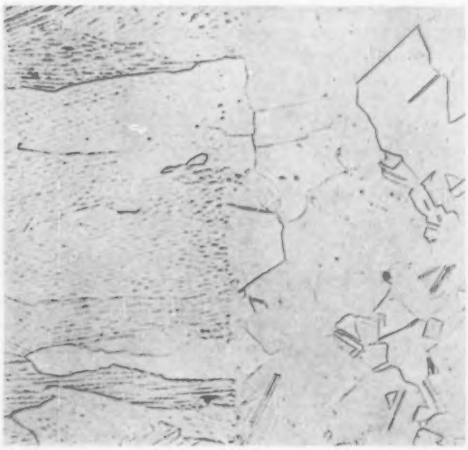

Fig. 23 Photomicrograph of weld interface aluminum-bronze test plate 10, (B169, Alloy A plate and wire). $FeCl_3$ Etch. 100 ×

Fig. 24 Photomicrograph of weld interface aluminum-bronze test plate 11, (B171-49 plate and ECu Al-A wire). $FeCl_3$ Etch. 100 ×

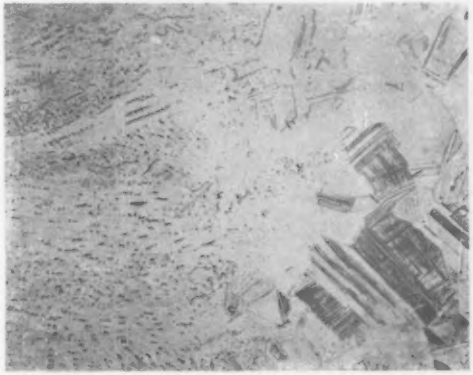

Fig. 25 Photomicrograph of weld interface silicon-bronze test plate 12, (B96, Alloy A plate and wire). $FeCl_3$ Etch. 100 ×

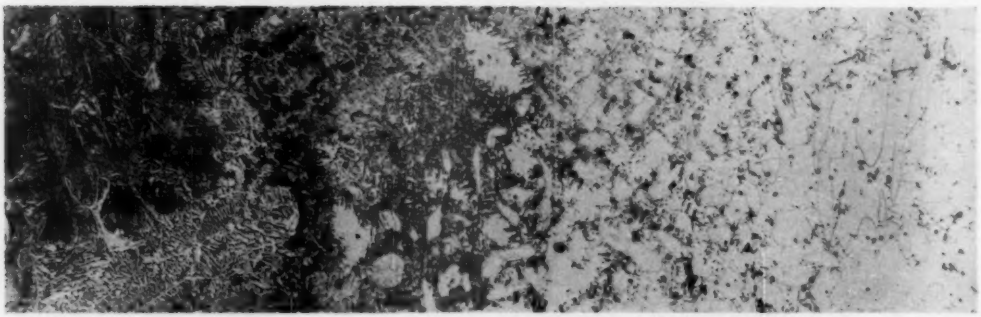

Fig. 26 Photomicrograph of weld interface manganese-bronze test plate 15, (B147, Alloy 8A plate and ECuAl-A wire) $FeCl_3$ Etch. 100 ×

shows a more gradual change in structure than in Fig. 21. Here again, the fine-grained Widmanstätten structure characteristic of this filler wire is evident.

The silicon-bronze, test plate 12, was made with a matching composition wire (Si 3.1%, Mn 1.1%), Fig. 25. The plate shows the characteristic twinned structure of a wrought alpha alloy. The deposited metal has the dendritic structure of a cast single-phase alloy with a perfect interface condition.

Test plate 15 is a $1^1/_2$-in. thick cast manganese-bronze marine propeller section welded with an ECuAl-A type filler wire, Fig. 26. The base metal shows massive alpha reeds in beta phase matrix contrasting sharply with the fine-grained deposit of the alpha-delta structure in the weld-metal zone. This is also shown in the fractured tensile specimens from this test plate, Fig. 17. Those specimens which broke in the base material are coarse grained, while those which fractured through the weld metal are extremely find grained. The ECuAl-A type deposits produce the maximum combination of strength and ductility in manganese-bronze joints of any electrode material so far available though variations in this basic composition may prove desirable. Figure 27 is the weld interface in test plate 22, deoxidized copper plate with silicon-bronze filler wire. The sound continuous interface condition is shown.

Fig. 27 Photomicrograph of weld interface deoxidized-copper test plate, (B159, DHP plate and ECuSi wire). $FeCl_3$ Etch. 100 ×

COMMERCIAL APPLICATION

While it is possible to present a thoroughly detailed outline of the laboratory work that has been done with Aircomatic welding of copper-base alloys, no such fortunate position exists when it comes to commercial experience. There are several reasons for this situation. Since the process is so new, there is a definitely limited number of commercial users, although there are fully enough to have proved it on a production basis. If it were possible to report most of the commercial results, the over-all picture could be filled in quite well. Special factors affecting important users of copper-base alloys sharply limit the cases which can be described, however, to a few representative instances.

There is a well-founded cloak of secrecy around much of the fabrication of the copper-base materials. Either

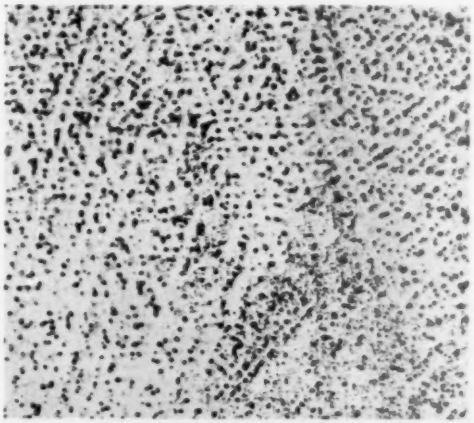

Fig. 28 Photomicrograph of leaded phosphor-bronze deposit showing even dispersion of lead. $FeCl_3$ Etch. 250 ×

because of competitive conditions, requiring close guarding of trade secrets, or because of military and other governmental security restrictions on the product, the great majority of major fabricators of copper and bronzes are not in a position to release even the minimum data about their work. It is an unfortunate circumstance, but such security requirements must be respected, and until a supplementary report can be made some months from now, when the field of use will have widened to include more of the nonrestricted applications, the few representative cases included here must suffice.

The research activities of the laboratory have been projected on a more nearly industrial basis within recent months, through the inclusion of this welding process in the studies of the Copper and Brass Research Assn., with highly encouraging results. It is anticipated that continuance of these studies will make available a great amount of particularly valuable information. Since this information will represent a collaboration between specialists in both Aircomatic welding and the copper-base metals, it is a reasonably safe prediction that it will be of wide general interest and a thoroughly practical guide for the industry.

One major industrial fabricator, working with deoxidized copper, made a rather detailed study of the procedures and results obtained on thicknesses of $^1/_4$ to 1 in., with the greater part of the work in flat butt joints of $^1/_4$ and $^1/_2$ in. thicknesses, using both manual and automatic welding methods.

On $^1/_4$-in. material with square butt joints, automatically welded, using $^1/_8$-in. deoxidized copper wire and a copper chill backup, without preheat, the welding conditions were: 540–550 amp. 25 v., 140 cu./ft./hr. helium flow, and 36 in./min. travel speed. One pass was welded from each side, the first pass being backchipped before the second pass, which was made with slightly lower current, gas flow and travel speed than the first.

The radiographic examination of this weld revealed a sound weld, with one spot of porosity. One half of the completed weld was peened on both sides and annealed at 1000° F. for $^1/_2$ hr. The other half was left as-welded. Macro, joint tensile and face- and root-bend specimens were sectioned from each half. The tensile tests are tabulated in Table 7, and the bend test results in Table 8. Both the as-welded and annealed specimens were free of crack or fissures, although the as-welded specimens contained some porosity, which was not found in the peened and annealed pieces.

All specimens, although they were felt to be satisfactory in results, indicated that the welding procedure could be improved. The tests did prove, however, that the welding process can be adapted to deoxidized copper with highly satisfactory results.

On $^1/_2$-in. copper, using a 90° double-bevel groove with above $^3/_{16}$-in. nose, the procedure included a 400° F. preheat, 530 amp., 28 v., 110 cu./ft./hr. helium flow, and 20 in./min. travel speed. Four passes were used to fill the groove, and the back was chipped $^3/_{16}$ in. deep and $^7/_{16}$ in. wide to insure complete penetration. Each layer of weld was peened. Results of the tensile and bend tests on these welds (Fig. 29) are tabulated in Tables 9 and 10. In this case, as in the $^1/_4$-in. thickness, there is evidence that the welding procedure can be improved, but since these tests were made, the procedures have been corrected, and this company is using the process in production work with good results.

Table 7—Tensile Properties of Aircomatic Welds in $^1/_4$-in. Deoxidized Copper

Specimen	*Stress yield point*	*Stress ultimate*	*Elongation in 2 in., %*	*Failure*
As-welded	8,930	32,500	45.5	$^5/_8$ in. from weld
As-welded	13,590	32,000	50.0	$^5/_8$ in. from weld
Peened and annealed	9,710	33,200	38.0	$^1/_4$ in. from weld
Peened and annealed	11,390	33,300	37.0	$^1/_4$ in. from weld

Table 8—Results of Bend Tests in $^1/_4$-in. Deoxidized Copper Welds

Specimen	*Elongation in weld, %*	*Degree of bend*	*Remarks*
As-welded	47.2	180	OK
As-welded	34.3	180	OK
Peened and annealed	25.0	180	OK
Peened and annealed	24.0	180	Small crack

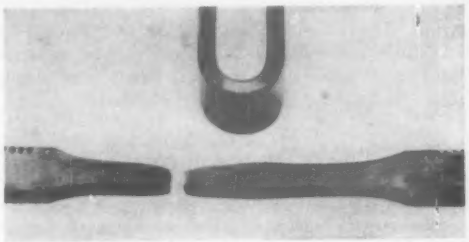

Fig. 29 Tensile and bend specimens of deoxidized copper

Table 9—Results of Tensile Tests on Welds in $^1/_2$-in Deoxidized Copper

Test No.	*Stress yield point*	*Stress ultimate*	*Elongation in 2 in., %*	*Failure*
40167-1	16,350	32,100	55.5	$1^1/_4$ in. from weld
40167-2	16,050	32,400	52.0	$1^1/_4$ in. from weld

Table 10—Results of Bend Tests on $^1/_2$-in. Deoxidized Copper Welds

Test No.	*Elongation in weld, %*	*Degree of bend*	*Remarks*
40167 FB	33.3	180	OK
40167 RB	17.0	180	OK
40167 LB	56.0	180	OK

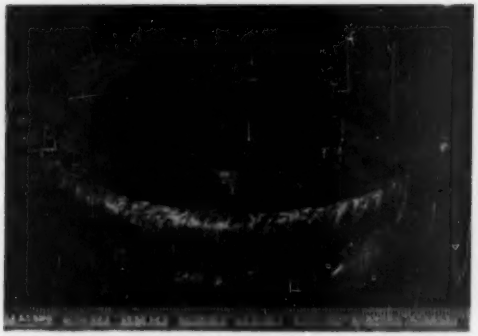

Fig. 30 Aluminum-bronze overlay on a part for chemicals process equipment. Deposit is smooth and homogeneous

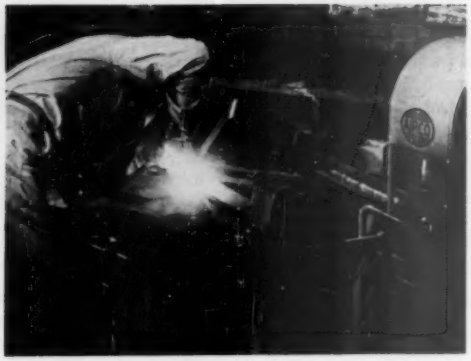

Fig. 31 Aircomatic welding of silicon bronze to form a tee section in agitator arms.

The economy of Aircomatic welding of copper is a function not only of sharply increased welding speeds with good quality welds, but also of the elimination or sharp reduction of preheat required without raising any of the problems associated with "cold" welding of this metal. The intensely hot, digging arc, using such very high amperages as mentioned above, achieves satisfactory penetration in copper much more readily than other methods of welding the material.

ALUMINUM BRONZE

The use of this welding process with aluminum-bronze wire for both joining and overlay work was described in some detail last year. Its development as an industrial application is an interesting example of collaborative effort between research and industry. A major fabricator of process equipment, with interest aroused by the initial success of the process on aluminum, worked very closely with laboratory engineers to develop techniques and procedures for Aircomatic deposition of aluminum bronze. They were using considerable quantities of this alloy for overlay work, and were having difficulties in obtaining efficiency and sound deposits with stick electrodes. The job required an overlay of metal which would be soft enough to form an effective and corrosion resistant metal-to-metal seal in large heavy duty valves, compressors and similar equipment.

Basic experiments and trials soon proved that this type of deposition of aluminum bronze would do everything required, and the operation was shifted from manual methods, used for testing, to fully automatic production work. Deposits (Fig. 30) are smooth, sound and rapidly made, superior to the previous method in both quality and efficiency, and the process has become standard in this plant, to the extent that as much as 75 lb. of bronze per day is being put down by a single automatic unit.

The next stage of development was extension of the operation to joining of dissimilar metals—joining of silicon-bronze baffle plates to a steel body, for example. This technique results in a joint of excellent strength, permitting the "spot" use of corrosion resistant or other special types of materials to a more effective degree, and saving appreciably in the cost of some fabricated assemblies.

Fig. 32 Silicon-bronze scraper arms after welding on a plate to form a tee. The tee end of the arm is later welded to a silicon-bronze casting

SILICON BRONZE

The silicon bronzes, welded with wire of matching analysis, have also proved a fertile field for this method of welding. Of a number of manufacturers who are using this method, none has yet encountered anything but gratifying results, in both economy and quality.

One of the first production applications on silicon bronze is illustrated in Figs. 31 and 32. The Martin-Quaid Co., Philadelphia, was asked to turn out a special type of agitator arm fabricated of $^3/_8$-in. silicon-bronze plate. It consisted of a long strip about $3^1/_2$ in. wide, bent to shape, and a shorter strip cut to fit against the bend and form a tee section on one end of the arm. This tee was produced by fillet welding with wire of matching analysis, and the tee end of the arm is then fitted and welded to a silicon-bronze casting by means of which it is mounted for use.

The fillet welds to form the tee section were made with 325 amp., 30 cu. ft. per hour argon flow, at a travel speed of 14–15 in. per minute, resulting in a full $^3/_8$-in. fillet weld with ample reinforcement. The welds are sound and mechanically satisfactory, and with the efficient transfer of all elements in the inert-gas-shielded metallic arc, the metal analysis is a practically perfect match.

Another leading fabricator, the Patterson-Kelley Co., Inc., E. Stroudsburg, Pa., has made excellent use of the process in the production of copper-silicon hot-water storage heaters ranging in size from 2 to 4 ft. in diameter, and up to 10 ft. or more in length. The shells of these units are fabricated of plates $^1/_8$ to 1 in. or more in thickness, using two, three or more plates depending upon which size mill product will yield the most economical product, and with dished and flanged heads and either cast or weld-fabricated fittings. Both manual- and automatic-welding methods are used.

Fig. 34. Finished fillet welds on the fittings on a 48-in. diameter silicon-bronze tank. Both are two-pass welds

A typical product is the 48- x 120-in. shell illustrated in Figs. 33 through 38. The shell is made of two $^1/_2$-in. plates, while the head is 0.525 in. thick. Preliminary assembly operations consist of welding the various fittings into the heads (Figs. 33 and 34) and joining the plates to form the shell. The fittings are welded in with 2-pass fillet welds, made downhand on a rotating positioner. The current for these welds is about 270 amp., with $^1/_{16}$-in. wire and argon gas.

The heads are welded to the shell on a roller-positioner (Fig. 35) at 30 to 40 ft. per hour travel speed (net) using two passes on the outside and one on the inside of

Fig. 33. Welding the manhole ring into a silicon-bronze head for a 48-in. diameter hot-water unit

The second pass has progressed a few inches, visible in front of the arc

Fig. 35 Welding the head-to-shell joint in a 48- x 96-in. silicon-bronze water heater-storage unit, which is rotated under the arc

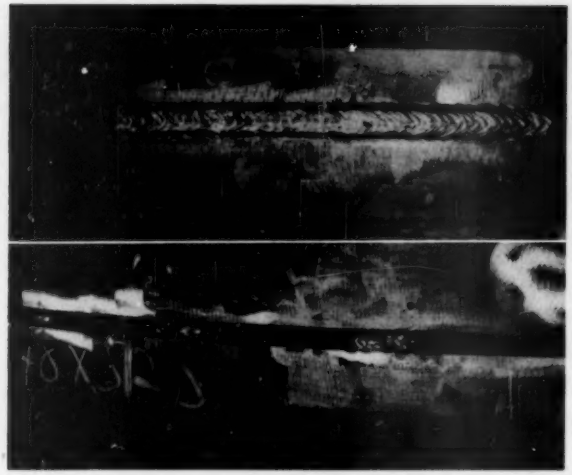

Fig. 36 Joint preparation and tacking of heat-to-shell weld on 48-in. silicon-bronze heater-storage units

Fig. 37 Finished weld on head-to-shell joint shown in Fig. 36

the tank. The joint (Figs. 36 and 37) is a vee groove, and 2-in. tacks are used to hold the part after alignment.

Figure 38 illustrates not only the 48- x 120-in. shell already described, but in the background a larger unit can be seen, which is made up of five plates. The technique used for this shell is somewhat different, designed to minimize rolling operations as well as fit-up and welding time. The five plates are welded flat, into two panels, by manual methods, and then are rolled so that only one girth seam is required in the cylindrical shape. This reduces the amount of positioning required, while still permitting the use of the most economical standard plate dimensions for the odd-length shell.

The same techniques apply to the plate for other sizes, and in most cases, the welding is done automatically, as illustrated in Figs. 39 and 40. This job is a 48- x 96-in. tank, using three $^1/_4$-in. plates for the shell, and the two "girth" seams are welded flat with the automatic unit. A single pass, using 375–425 amp. on a $^1/_8$-in. wire, and a mixture of helium and argon gases for shielding, completes the weld at a travel speed of 180 ft. per hour.

Then, after welding flat, the composit sheet is rolled, as shown in Fig. 41, to form the cylinder. The ends of the plates are staggered in welding them together, so that the longitudinal joint in the shell is not a straight line. The ductility and smoothness of the welds precludes any difficulties in rolling the material, and it can be handled just as if it were a single mill plate. The remainder of the operation on this tank (installation of fittings, heads, etc.) is similar to that described for the 48- x 120-in. unit.

Figure 42 illustrates a 24-in. unit, of $^1/_4$-in. material, which is manually welded with a single pass. The entire range of these hot-water storage heaters is produced with very much the same basic procedures, regardless of size, and they are all made to the highest weld-quality requirements.

The Patterson-Kelley Co., Inc., is the first large-scale user of silicon bronze to qualify the process for that metal under the A.S.M.E. Boiler Code, which they must use as a standard for all such production. The specimens illustrated in Fig. 43, together with the data presented in Table 11, are representative of the results obtained in the code tests, which have qualified the process, as of October 1st, up to $^3/_8$ in. in thickness. Qualification is being secured on 1-in. material, and judging from experience already gained, this further qualification is only a matter of time and adjustment.

Fig. 38 Foreground silicon-bronze water heater-storage unit is 48 x 96 in., background unit 48 x 120 in.

Shell of the longer unit is built up of five plates, with all but one girth weld done before rolling into cylindrical form

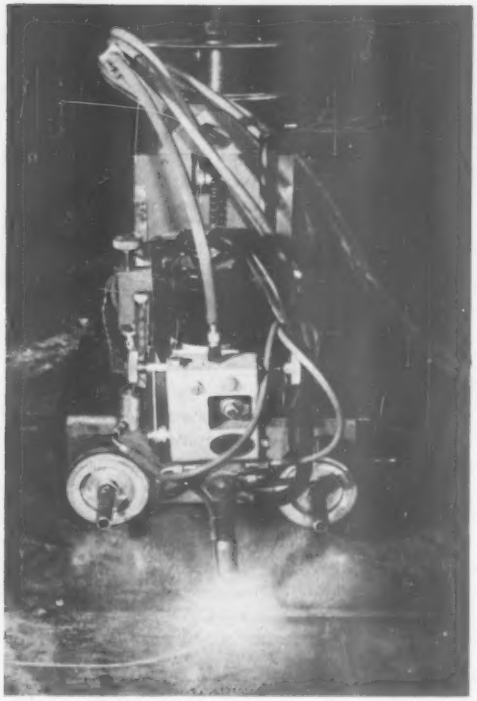

Fig. 39 Automatic welding unit, welding "girth" seams in 1/2-in. silicon-bronze flat, prior to rolling, at a travel speed of 180 ft. per minute

Fig. 40 Automatic welding unit, from the control-station side, during welding of 1/4-in. silicon-bronze plate

Fig. 41 Rolling a panel of three welded plates (Figs. 38 and 39) to form cylindrical shell for a large silicon-bronze water heater-storage unit. Note the staggered alignment of the assembly

Fig. 42 Welding a 24-in. diameter silicon-bronze water heater unit

Techniques and results are comparable from the smallest to the largest assemblies

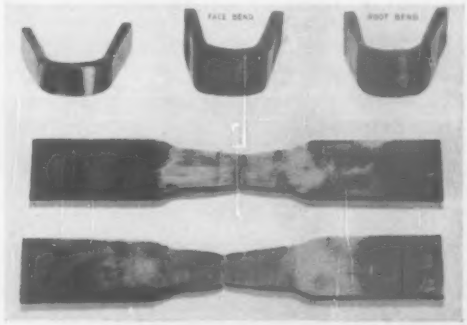

Fig. 43 A.S.M.E. boiler code silicon-bronze qualification specimens (see Table II)

All but the upper left specimen are 3/8-in. material. That one is a side bend on 1-in. silicon bronze

Table 11—Typical Tests on Aircomatic Welds in $^3/_8$-in. Silicon-Bronze Made According to A.S.M.E. Boiler Code and Qualified

Specimen No.	Width	Thickness	Area	Ultimate load, psi.	Ultimate strength, psi.	Location of fracture
FW1	1.495	0.385	0.576	32,500	56,420	In weld
FW2	1.479	0.382	0.565	32,000	56,640	In weld

The savings possible in the Patterson-Kelley Co., Inc., plant with this process have not yet been fully explored. It is obvious, however, that welding copper silicon at speeds such as 180 ft. per hour is a great deal faster than any other method, and since the welds are of excellent quality and require no particular finishing or clean-up measures, the savings are very sizable. This is particularly true of the automatic operation, where the human factor is all but eliminated, but it applies in a considerable degree also to the manual work.

MISCELLANEOUS

Among the successful applications which, while still relatively minor, may lead to important uses of the process on copper-base materials is its use for rebuilding steel sheet mill guides, such as those illustrated in Fig. 44. These guides, which are designed for sacrificial wear to protect the edges of steel sheet in the mill, require a soft buildup, yet one which will have reasonable durability. The base metal of the guides varies considerably in its analysis, but is generally a leaded phosphor tin bronze, which can be rebuilt with either a similar type of phosphor bronze or with aluminum bronze.

These guides are a steadily recurrent maintenance problem in steel mills, with a service life between repairs sometimes of only a few hours, and they have been a difficult job because of the preheat required to weld them by other methods. With this method of welding, the only preparation usually required is thorough cleaning, such as vapor degreasing, and welding is very rapid, with a minimum of finishing and no apparent distortion. By elimination of the preheat and the elaborate preparation measures previously required, and by the high speed of welding, (deposition of 10–12 lb./hr. per piece, gross welding time less than 10 min.) the process promises to create considerable savings in this operation.

Elsewhere in steel-mill work, promising experiments are being carried out on copper tuyère cooler repairs, and in this troublesome job, previously done with preheating and gas welding, the newer inert-gas-shielded metallic-arc process has given indications that it will be an excellent tool for fast and simple repairs.

Considerable successful work has also been done on propeller repairs for ships of all sizes. Such parts are usually welded with aluminum bronze, and wherever a color match is unimportant, this method produces a repair of highly satisfactory mechanical and physical properties.

It is obvious that these industrial cases are a scattered representation of only a few highlights. They are, however, fully representative of the general picture of industrial application of the process to copper-base materials and the general success of its commercial uses.

CONCLUSIONS

1. High-quality deposits of excellent appearance can be made with the Aircomatic process using several grades of aluminum-bronze, silicon-bronze and deoxidized-copper electrode filler wires. These deposits can be made at high speed and in all positions. Welding is relatively simple and special skills or operator techniques are not required.

2. Properties of welded joints in bronze plate made with the proper filler wire compare favorably with minimum properties of base material.

3. Copper-zinc alloys are difficult to deposit but satisfactory joints can be made in copper-zinc base materials with aluminum-bronze (ECuAl-A) electrode wire.

4. Phosphor bronze and leaded phosphor bronze can be applied in those applications where a certain amount of pinhole porosity is permissible.

5. Limited, but adequate, commercial use of the process indicates that it is a successful production operation for deoxidized copper, aluminum-bronze, silicon-bronze and other copper-base alloys.

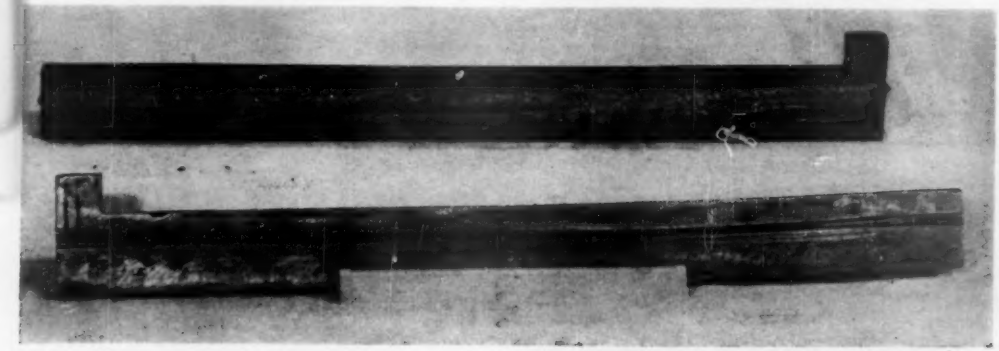

Fig. 44 Steel mill guides, of phosphor-tin bronze, before and after aircomatic weld buildup

ACKNOWLEDGMENT

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Nomenclature Used for Designating Properties of Materials

by R. Alden Webster

IN RECENT years confusion has developed in naming the properties that are exhibited by materials, evaluation of which has become almost a fetish with industry. Since World War I we have become more and more a research-minded industrial nation, delving into the many-phased secrets of natural and manufactured articles. This curiosity is evidenced in conference, in forum, in print and in the multifold products that are coming off in almost, if not quite, continuous streams of production. To name properly the properties to which we are referring continually would seem to be a not too difficult matter; but a division has developed, resulting in two schools of application.

In this article the so-called *mechanical* and *physical* properties will be discussed in an attempt to clarify and to arrive at definitive statements. With these factors in mind it is well to set up a basic definition of each.

Mechanical properties are those exhibited by a mechanism, device, or structure as the result of *design*. To delimit these properties the conditions encompassing the capacity of mechanisms will be necessary to apply.

Physical properties are *inherent* in the material or materials of which mechanisms, devices, or structures are built. This definition coupled with the definition under "mechanical properties" given on page 9 of *Metals Handbook, 1948*, delimits physical properties. Here the elasticity and ponderability of materials are covered. Other properties that are inherent in the material have special designations such as electrical, magnetic, thermal, etc. For these, do not use "physical," since it will be confusing (possibly few ever do).

The resultant design or device may be simple or complex, but it has a number of mechanical properties, which may be of more or less importance in its functioning depending upon the use or uses for which designed. The following may be considered as some of the many that are used in industry:

Dimensions	Draw-bar pull
Weight	Tractive effort
Fatigue	Load capacity (including overload)
Speed	
Endurance	Volume capacity
Cutting capacity	Deviation (deflection) under load, etc.
Period of vibration	

Now consider the materials entering into the parts making up the structure. These may be few or many, but each is a distinct material and its inherent properties depend upon previous processing as well as its constituency. Among the inherent properties are the physical, among which some common ones are as follows:

Tensile, compressive, and torsional properties
Hardness
Toughness
Ductility
Malleability
Density
Friction, etc.

Possibly part of the misunderstanding has come about because we do not entitle our tests properly to indicate what they really are. For instance we say "physical tests" when we mean "physical-property tests." It does not affect the name of a property whether a mechanical or other test is used to determine it. Physical (or other) properties are not changed by the nature of that test. For instance, a chemical-property test may be accomplished by either a chemical or a spectrographic test. This may be hair-splitting but it is based on word meaning and usage. If the difference in the meanings of nounal modifiers and descriptive adjectives is considered, the above will be clear. However, nobody today will go to such pains as to call the proper designation, and the term "physical test" will continue to be used to designate "physical-property test." So it behooves us to accept it as meaning just that; but it never should be called a "mechanical test," even though accomplished by a mechanical test.

In concluding it will be seen that first we must distinguish between the fundamental concepts of *mechanical* and *physical*, viz., pertaining to device (designed) or pertaining to the material (inherent). Then in completing the definition we apply the factors that place the two in the proper category, i.e., applying to elasticity and ponderability. Many other properties or conditions have been given definite entitlements which set them apart from mechanical and physical properties and these nomenclatures should preferably be used in order to reduce confusion. Specific definitions and usages tend to make a clearer understanding. As a final admonition, do not distort word meanings in an attempt to arrive at some desired condition.

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These statements are the views of the author and are not necessarily those having the approval of the Office, Chief of Ordnance.

General Procedures for Fabrication of Pressure Vessels

A general procedure is outlined for the fabrication by welding. Special attention is devoted to drawings, specifications, material, layout, forming, fittings, assemblies, welding, inspection, stress relieving and final testing

by S. V. Williams

THE purpose of this paper is to stimulate interest on the part of fabricators in a general procedure for the fabrication of pressure vessels, so that this industry can be upgraded and the quality of pressure vessels improved. It is felt that this should be a stabilizing influence in the industry.

It is generally recognized that fusion welding is the best method for the fabrication of pressure vessels, and on this basis, this procedure is essentially set up for fabrication by fusion welding.

It is submitted as a tentative procedure with the thoughts that each fabricator interested in upgrading his fabrication would use it as a guiding outline for establishing his own procedure. This challenge must be met, as the free competitive enterprise system demands it.

GENERAL GOVERNING PRINCIPLES OF A FABRICATION PROCEDURE

Since the fabrication is carried on by the Production Dept. under the scrutinizing eyes of the Inspection Dept., these two departments must function independently as to supervision, and the heads of each shall be kept independent, responsible only to top management. This principle is often ignored, and in doing so, the free enterprise method is not truly effective, as too often the Inspection Dept. does not function as an independent unit, often being under production supervision, which naturally limits its freedom and its true value in establishing the facts and preventing errors and the misapplication of materials and drawings at the start of the fabrication of a particular order. In short, it is impossible for the manager of a fabricating shop to manage the shop and be his own referee at the same time, without being unduly influenced in making impartial decisions on critical items.

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Production orders or shop orders establish the authority to start the fabrication, and should state the engineering specifications and blueprint drawing to which both the Production and Inspection Depts. work. They are the laws under which the Production and Inspection Depts. must operate. This does not mean that the two departments shall not cooperate in carrying on the fabrication, for it is a basic principle that the Inspection Dept. should never hold back production. Inspection, however, must be allowed time to carry out their operation of inspection, so that all previous work carried out either on parts, subassemblies or assemblies, as well as the material used, are independently checked against the specifications and drawing requirements. This assures that any subsequent work will not have been carried out on faulty parts of materials, and that actual productive hours will come nearer to the estimated hours upon which the burden is figured.

Changes to the engineering specification and blueprint drawings should be made only by the Engineering Dept., and these changes must be approved by the customer. This does not limit either the Production Dept. or the Inspection Dept. from asking for changes, if in their opinion such changes would improve the quality and reduce the cost of the part or assembly being fabricated. However, as stated above, neither department has the authority to make changes to specification or blueprints.

Each piece of material on the drawings shall be covered by an item number, identifying that piece on the bill of material. The bill of material naturally gives the details as to type of material, material specifications, quantity, form and size of materials required to fabricate the product specified on the order. This coordination between the drawings and the bill of material readily enables all departments to identify each detailed piece of material, as the purchase orders for said material should include the item number and information imparted by the bill of material. With this additional coordination with the Purchasing Dept., incoming material can be correctly stored and placed in the production area requiring its use in the operational

sequence of fabricating the pressure vessel ordered.

Specifications must cover all demands and requirements of both customer, codes, state and government agencies. It is not the job of the Production or Inspection Depts. to see that these agency requirements are met. That is the function of the Engineering Dept. The Production and Inspection Depts., when informed by the specifications, will then see that these requirements are complied with.

Plans or methods of fabrication should be established under standard manufacturing procedures so that both the Production and Inspection Depts.' supervision can coordinate their independent functions with no delays to production. This is generally best accomplished through a production meeting, at which both departments are represented by their key men. At such a meeting, the Inspection Dept. should caution the Production Dept. of critical tests or dimensions, and explain their method of making their checks, so that both departments, while functioning independently, still have the same base point or bench mark to start with. It is not, however, the function of the Inspection Dept. to tell the Production Dept. how they shall carry out their production. They must, however, explain what preparations are necessary to make the part, weldment or vessel acceptable for carrying out the destructive tests and the final tests stipulated.

No materials or purchased parts shall be placed in production until they have been released by the Inspection Dept. The Inspection Dept. must check such material and specifications against the bills of material and certified test reports to see that specifications have been complied with. This is fundamental principle, if negligence is to be avoided, and economical and quality production is to be carried out. Too often this procedure is taken for granted and overlooked or ignored by those who try to make short cuts.

MATERIAL

The A.S.T.M. or A.S.M.E. Standards are generally referred to on material. The materials generally used are rolled plate, forgings, castings, weldments or tubing, and are specified on the fills of material. They are the physical starting point of a fabricated pressure vessel, and hence can be considered of basic importance. Positive information should be established as to their soundness or physical condition and dimensional accuracy, particularly as to wall thickness and strength-carrying ability. In other words, materials can be considered the foundation upon which fabrication is to take place, and hence it must be sound and correct. As has been pointed out, no materials should be placed in production which have not been released by the Inspection Dept.

All incoming plates should be checked for size against the bill of material and the purchase order issued. Sizes and thicknesses must be correct. The heat number should be recorded so that the type of steel is checked against that specified. This naturally takes into account commercial tolerances which are established by the American Iron and Steel Institute for material by the ability of the steel mills to meet the tolerances agreed upon. While the dimensions may vary slightly, the thickness in no case should be under that minimum specified.

The top and bottom, sides and edges of all plates should be inspected for injurious defects such as laminations, blisters, pits, scales, snakes, cracked seams, etc.

As stated, all plate material should bear a proper identification or heat number to tie in with the chemical and physical requirements of the specifications. This is generally placed on the plate surface that becomes the outside of the vessel, to assure that internal corrosion does not remove this identification when the vessel is placed in service, and so that it can be readily found. This naturally implies that before any plate is cut up, the heat numbers or identification numbers should be properly stamped on each of the component parts. In all cases, it will be necessary to have this verified by the Inspection Dept., and in many cases, by the customer's own inspection.

Since in most cases the heads are of rolled plate, everything that has been said above would apply to the heads.

Where forgings are used, it will be found that they are will generally have a machined surface. If not, their surface should be sandblasted before inspection is made, to remove all forging scales, and as stipulated heretofore, proper identifications should be stamped thereon to identify it at all times, and properly tie in the chemical and physical properties of the specification stipulated.

It has been found advisable where heavy forgings or plate are used to make a sulphur print to assure that sulphur segregations are not present in the surfaces to be welded against.

When castings are used, it is best to be sure that they are sound and free from internal defects before they are placed in production or assembled to other component parts. As has been stated, the surface should be cleaned up, and if not machined, sandblasted so that proper inspection of its surfaces can be carried out, either visually or with magnaflux, etc. Should extensive machining be carried out and tightness of the castings is required, it is advisable to subject castings to a non-destructive test by X-raying, etc., before additional work or fabrication is carried out using said castings.

Should weldments be procured instead of forgings or castings, the material of these shall be verified and the fitness of the weldment and workmanship thereof checked, as well as dimensions, before said weldment is placed into fabrication.

In many cases, it would be most economical to make up nozzles or internal parts out of piping or tubing. In such cases, the tubing specified by the bill of material must be checked for surface defects, both internally and externally, as well as to mechanical dimensions pertaining particularly to the minimum wall thickness,

before such tubing is placed in fabrication.

Should any of the material be rejected, the supplier of such equipment should be consulted, and given an opportunity to either replace or consent to a backcharge for repairing, if, in the opinion of the Inspection Dept., with the customer's approval, suitable repairs can be made.

Before fabrication is started, all materials should be present in the shop, or present—accounted for. Unless this practice is carried out, the production space may become a storehouse, and excessive costs encountered, with loss of production and delayed shipments.

LAYOUT FOR CONSTRUCTION

As a general practice, all layout work should be carried out in the flat. This, however, is limited in those cases where experience or know-how has not been gained so as to anticipate shrinkage from welding, forming, etc. To carry out this work with minimum delays naturally implies that the materials received have been properly marked with identifications as to order number, and placed in such storage as to facilitate their easy transport to the layout or assembly floor, depending on next operation.

The materials to be laid out should bear a rider or identification indicating that they have been released for production by the Inspection Dept. In the case of flat plate, the top surface generally becomes the outside of the finished vessel. This enables all the proper identifications to be applied, such as heat numbers and X-ray markings where required, and reference lines for shearing or gas cutting.

In preparing the edges for gas cutting or machining, it has been found expedient for the layout man to draw a sketch of the land or scarf required on each edge. As a general rule, it will be found satisfactory to scarf all four edges. As intimated, this may be carried out satisfactorily by gas cutting or machining, and the accuracy of the finished structure will depend in a large measure on the accuracy of this scarfing. As mentioned above, the know-how of the shop must be used in determining allowances to take care of shrinkage from welding or other characteristics of the manufacturing facilities.

While machining often exposes inherent defects in the material, it has been found that gas cutting, because of the concentration of heat, will often expose and reveal defects which might be overlooked in the machining.

In some cases, it will be found advisable to carry out the layout work after much of the fabrication is completed, in order to compensate for the unknowns of the shop know-how. We speak particularly of nozzle necks and connections, which must be maintained as to height, yet flush with the inside of the vessel.

In those cases where extreme accuracy must be maintained, such as for machined parts, the layout work should be carried out on the subassemblies. This naturally assumes that the machined surfaces will not be affected by the subsequent fitting and welding. In other words, they will be far enough away from the weld area to eliminate distortion. For assurance of higher degrees of accuracy, the subassemblies should be stress relieved to assure stability in the materials.

Those component parts which will lap over other parts in the fitting up or assembly, whereby a void space or air pocket may be sealed off by subsequent welding, should be properly vented by drilling $^1/_8$-in. hole through the plate. This is called a telltale hole. In many cases this telltale hole can be used to advantage in testing the tightness of the welds joining such parts to the vessel proper. This would apply to reinforcing collars or welding nozzles wherein the reinforcement is built integrally with the nozzle, etc.

FORMING

As a general practice, the materials to be formed should be in an annealed or stress-relieved condition, to assure that the additional fabrication stresses set up by rolling or forming will not use up the material's ability to deform, elongate, or stretch, indicated by cracking or even failure.

Before gas cutting is started, the type of material must be known and considered to assure that thermo-shock or stresses will not cause incipient cracks to form in the gas cut edges. Preheating may be required. Wherever possible, this gas cutting should be carried out with templates or by mechanical means, such as Travelgraphs, Planographs, etc., to develop the degree of accuracy which can be carried out with gas cutting when it is properly executed.

In many cases, shearing will be satisfactory, and in this case, the type of steel must be considered and the temperature thereof as spoken of previously, so that no damage is done to the edges subjected to the shearing force. Where flat surfaces must be maintained, the drag from the shearing should be held to a minimum, and then placed on the top side or that surface opposite from the one being put in contact with another component part. Should punching be resorted to, the same general practice should be followed as for shearing.

In forming by pressing or rolling, the amount of deformation taking place in any one pass should be not only adjusted to the type of material, but also to the radius or curvature to which the forming is to be carried out. Generally, the thicker materials employed in fabrication will require that this be done in steps, and it may be found advisable on the higher strength materials to start out with an annealed state, and for severe forming, interpose the steps with repetitions of annealing or stress relieving. As experience is gained from pressing and rolling, the know-how spoken of previously becomes important, if high degrees of accuracy are required. In other words, the characteristics of each set of dies or each set of rolls must be known, if a rolled or formed section is to be accomplished with squared and straight meeting edges. If this cannot be accomplished, it will be necessary to relayout and gas cut after pressing and forming.

Should forming be carried out by hand, considerable care and precaution shall be exercised to eliminate overheating of the metal, resulting in heavy scale and also damaging the surface through hammer marks, etc. As a general rule, this type of forming is only resorted to when other types cannot possibly be carried out. The workmanship of such forming greatly depends on the skill of the workman.

As stated before, where the end closures consist of forgings with predetermined periphery, this periphery must be known before the component end sections are rolled, so that the offset between these parts will not exceed the tolerances.

Particular attention must be paid to the maintaining of either the I.D., or O.D. whichever is specified, as in many cases variables in thickness of the material will not permit both to be held. Generally it is impossible to hold both the I.D. and the O.D., even if the plate thickness is exact.

It is considered good practice to obtain a reasonable degree of accuracy in the forming, to assure minimum time in the fitting up of the component parts, in other words, the ends of flat plates should be broke to the correct radius before they are rolled to that curvature. In most cases, it will be impossible to take this flatness out after the plates are rolled into cylindrical form. With these meeting ends formed to the correct curvature, it then becomes possible to hold them in place with clamps when the rolling is completed, and thus facilitate fitting up. This not only applies to cylinders of heavy thickness, but also to cylinders of lighter wall, which may tend to collapse or go oval from their own weight.

Should forming require a machining operation, or where surfaces are machined to accomplish the forming desired, the surfaces should be protected during the subsequent forming and fabrication operations. This is particularly true of gasket surfaces, grooves, etc.

PRELIMINARY INSPECTION

Should preliminary inspections be required by customer's inspector or other inspection agencies, it is advisable to have this carried out at this point, before sections are put together. This permits thicknesses to be measured and proper identification of the material to be checked to assure that his requirements are being complied with. Such inspections may be demanded by the customer, insurance company or the state regulations applicable to the order.

FITTING DETAILS AND ASSEMBLIES

To reduce costs and improve workmanship, as well as accuracy, special fixtures or jigs should be used wherever there is a repetition of said parts or details. In making up these fixtures or jigs, a trial fixture or jig should be used wherever there is a repetition of said parts or details. In making up these fixtures or jigs, trial specimens should be run through and verification of the accuracy determined by the Inspection Dept. before said jig or fixture is released for production. In a few cases, it may be found necessary to complete the assembly and welding and insert the entire jig in the furnace for stress relieving before the part is removed from the jig. Generally speaking, however, allowance can be made in the design of the jig to take care of spring back or shrinkage, so that the jig operator will not be tied up or an excessive number of jigs required to carry on the production rate desired.

This procedure covers fabrication by welding. This implies that material and parts will be subjected to thermo temperature stresses, and as the shape of the material or parts may be changed by these thermo stresses, allowance must be made for this shrinkage or change in dimension or shape. The know-how of the shop will enable these to be anticipated, and allowance can be made. In other words, it is best to anticipate that there will be some variations, and in fitting-up and assembling, allowances should be made for this. In some cases this can be compensated for by a slight adjustment in the meeting edges of the component parts, however, this correction or allowance cannot exceed the tolerances permitted for offsets or misalignment, and cannot be tolerated in highly stressed parts or areas, or where close machining is required.

Before fitting-up is started, the edges of the meeting parts must be correctly prepared for the type of welding which is to be carried out. In other words, the welders should not be called upon to correct poor fit-ups. Such practice leads to faulty welding, and high costs. Should corrections be required and be made by gas cutting, these meeting edges should be again prepared and cleaned up, either by chipping or grinding to present a suitable surface for the subsequent welding.

While some allowance is made for misalignment of meeting parts, such misalignment indicates faulty workmanship, and should not be permitted. In other words, if our layout and forming has been correctly carried out, the alignment of the meeting parts should present a streamlined appearance, and thus utilize the full value of a fusion-welded joint.

In no case should we expect the welding to correct for misalignment of meeting edges. If anything, it may aggravate the condition, particularly as the thermo stresses set up by welding may be concentrated at the edges of such misalignment.

To maintain the alignments and dimensional accuracy required, fitting tacks or lugs are generally employed. In using tack welding, care must be exercised in not damaging the surrounding surface, or where lugs are required, the fillet welds should not undercut parent plate, requiring excessive repairs to later be made when said lugs are removed. Generally, it will be found necessary to remove said tacks. The tacks must be heavy or strong enough to maintain the alignment during the welding operation.

If jacks or fixtures are used, the amount of tack welds or lugs will naturally be reduced to a minimum, and in many cases, will not require removal.

Reinforcement of openings, when in the form of a reinforcement collar or pad, must be correctly shaped to the contour of the part being reinforced, so that metal to metal contact can be established with a minimum of void space between meeting surfaces. Should these reinforcements be of unusual heaviness, means must be taken to blend them in with the shell, so as to eliminate the intensification of operating stresses at their extremities. As mentioned previously, adequate means must be taken to vent said spaces, so that excessive stresses are not set up during the welding or subsequent stress-relieving operations.

Where extreme accuracies are required, it may be necessary to machine subassemblies in order to arrive at the dimensional accuracy required.

Should such machining be required, it will generally be found necessary to stress relieve said subassemblies to assure a degree of accuracy which can be maintained when good practice is carried out. Good workmanship indicates that a definite procedure has been followed in fitting up to assure repetitive results.

In no case should we expect poor fit-ups on assemblies to be corrected by the subsequent fabrication operations. This will be found to be wishful thinking, and result definitely in poor workmanship and added expense. As intimated, these are points to be particularly checked by the Inspection Dept.

WELDING

Modern fusion welding is one of the great inventions but, like fire, cannot be played with, if troubles are to be avoided. For this reason, the AMERICAN WELDING SOCIETY has established tests for qualifying welding processes and also qualifying welders. These are published and have been accepted by most of the leading engineering societies as standards to go by.

Qualification of the welding processes is set up by the American Society of Mechanical Engineers, Section 9 of their Boiler Code. Such tests should be complied with before the fabrication of a pressure vessel is started.

Welders' qualification or operators' qualification is also covered by the A.S.M.E., Section 9 of the Boiler Code. These qualifications should be complied with before welders or operators are permitted to work on Code work, and should be established for all welders if troubles are to be avoided and quality workmanship established in carrying out fabrication of pressure vessels.

The welders' qualification records should be kept current, and this can be economically carried out by distributing vessel test plates among the different welders.

For upgrading the welding and securing of repetitively high quality, the welding engineer must establish his procedures, and hence give much forethought in the choosing of his welding processes. These will generally be either of a manual type or automatic type.

(*A*) Manual welding naturally has to be carried out where the work cannot be positioned or where the length of any weld is short and time required to set up would be greater than the time required to complete the welding. The human equation is greater in manual welding. However, it does allow for more detailed observations to be made of the welding pool, this indicating the behavior of the materials of both the filler and parent plate. Its quality, therefore, will be shown by testing to be equal to that of automatic welding, and acceptable to established Code standards. As a flexible process, it is not surpassed. However, competition by automatic welding limits its use in fabricating pressure vessels.

(*B*) Automatic welding has competitively established itself where repetition of setup can be used, as the process is more continuous and the fatiguing action on the welders less severe. Its quality can be checked, and for acceptable work, it demands better materials and better preparation, as well as fit-up, and is therefore an upgrading process in the fabrication of pressure vessels.

Code test plates must be covered by bills of material, and their material should be the same (preferably of the same heat of steel) as that used in the vessel proper.

The test plates themselves should be welded as soon as the welding fabrication is started, and the destructive tests carried out on these test plates to assure the quality complies with the specifications before welding has progressed to a state where extensive replacement might be necessary. In other words, the test is a test of the quality of the welding to be carried out on the said material, and is proof that the welding procedure, as well as the welders, are satisfactory for quality fabrication on the materials being used.

For good quality and competitive welding, the work is positioned for downhand welding in a continuous manner. Rotating of cylindrical vessels or movement of the parts should be carried out for both manual and automatic welding. In the case of automatic welding, the head can travel along the weld.

Adequate support for holding parts to be welded to desired or formed shapes should be used in minimizing distortion and loss of shape or unevenness of the joining parts.

To minimize distortion and control same, the sequence procedure for welding, once established, should be maintained to assure repetitive results. When preheating is required by the welding procedure, this should be uniform, particularly when welding is resumed after change of shifts or shutdown from a breakdown or lunch hours.

Preparation of the welding groove to specifications and dimensions, as well as surface conditions, must be complied with, if competitive time is to be made with quality requirements the customer can demand. Each welder has a right to reject poor preparation, and have it corrected by chipping or grinding, or where the groove is too wide, he should receive a credit for the extra time

required, chargeable to the department responsible for the poor preparation.

The welding procedure, having been established, should be followed, using electrode type, size, amperage and voltage and speed of travel, called for. A record of this should be maintained, and this tied in with the welder's identification stamped on the work.

The welding procedure must set up the preheat, as well as the postheat temperature, and as has been stated, the sequence of heating should be followed, and temperature checked, with suitable equipment afforded the welder who is held responsible.

Back chipping or other suitable means must be taken to prepare for welding of the back or opposite sides, particularly if the joints cannot be X-rayed or X-ray is not stipulated. Generally, tack welds are removed. This can best be carried out by chipping (until no chip splits). Depth of back chip should assure that all weld metal in the weld is the same as the welding procedure called for, and is in agreement with that used in making test plates.

The preparation of the welding surfaces for X-ray must be such as to permit a readable X-ray to be taken. The weld surface must be smooth and free from surface imperfections that could be misinterpreted as defects in the weld cross section, thus eliminating the possibility of covering up any subsurface defects in alignment with surface defects.

Should the welds be ground flush, undergrinding in turn must be guarded against, as it is picked up by the X-rays. As has been stated, the plate surface must be free of fitting up tacks or clamp marks. The X-ray not only reveals the weld, but also the weld area, and to be read correctly, no surface marking in either weld or weld area should be showing.

FINAL ASSEMBLIES

Before final assembly is made, the Inspection Dept. should release sections or parts of the vessel being assembled, to assure that all work has been carried out correctly, and that all internals required are assembled or installed, as the opening thereafter is generally confined to manways.

The over-all dimensions and orientation of all nozzles in the cylinder and top and bottom heads must be checked before the final closing weld is made. Alignment of meeting edges of the section or subassemblies must be within Code allowances, and the nozzles oriented in such a manner as to be easily made up with companion meeting flanges.

All internals must be checked for orientation and such reference marks placed on the outside of the vessel, to assure their correct orientation when complete assembly has been carried out. In short, this orientation must be correct with external center lines.

Four center lines should be used, and any permitted variances between the two meeting parts should be equally distributed over each quadrant.

The machining requirements must be checked at the time of assembly to make sure that this can be carried out after the vessel is completed.

For a high degree of accuracy, the final machining should be carried out after final assembly, welding, X-ray and stress relief.

For holding alignment and orientation and dimensional accuracy, adequate tacks or assembly lugs must be employed. In many cases, additional stiffening fixtures will be required to meet roundness and other dimensional tolerances. As stated above, the welding itself will not correct poor fit-up or preparation.

MAGNAFLUX INSPECTION

Magneflux inspection is generally used on component parts before they are assembled into the final vessel. As a general procedure, magnaflux is not required for the main body of the pressure vessel.

When the steel of a pressure vessel is other than that generally used and specified, and therefore where it may contain unknown factors, precaution by magnaflux inspection pays out. Should the sections be heavy solid plate which approach a cast condition or a rough forging, it will be found expedient to magnaflux the meeting edges. This precaution will expose conditions which could cause welding difficulty and trouble.

For nonmagnetic vessels, a similar type of test, known as Zygloing, can be used with good results.

Where pressure vessels are to be subjected to rapid changes in temperature, either of subzero or elevated temperature, magnaflux inspection should become a part of the fabrication procedure.

X-RAY INSPECTION

A procedure for the fabrication of pressure vessels to meet Code requirements demands X-ray inspection be carried out. For the checking of welding processes and welding qualifications, it is a most useful test. Also, it can be used to solve problems which result from negligence on the part of the fabricator.

A general procedure for the fabrication of pressure vessels should embody X-ray inspection. Competition demands that fabricators have X-ray facilities to keep them out of trouble with their materials and workmanship. X-ray is a quality control measure, and until our materials reach a higher state of perfection, it must be considered in setting up any procedure for fabricating pressure vessels.

INSPECTION

The free enterprise system makes it competitively necessary for fabricators to have adequate inspection in their own shop, and as stated above, this must be independent of the production supervision, if its true value is to be realized. The Inspection Department is not competing with the Production Department.

Its competition is the inspection carried out in the competitor's shop. Therefore, its checking must be accurate and correct, so as to win the admiration of the Production Department, as well as the respect of its competition.

To carry out inspection correctly, the completed vessel should have the following steps checked before stress relieving or testing.

All dimensions, alignment and orientation should be checked.

The general appearance and surface conditions, both inside and outside the vessels, must be rechecked.

All external and internal parts to be welded to the vessel must be correctly dimensioned and oriented.

All confined air pockets should be vented, and those around reinforced openings should be tested to assure tightness of said connection.

All finished machined surfaces should be coated to minimize oxidation during stress relieving.

A written release should be given by the Inspection Dept. for stress relieving.

STRESS RELIEVING

Stress relieving is carried-out to reduce the fabricating stresses set up in the pressure vessel, and is covered by the Codes. Before subjecting the vessel to the stress-relieving operation called for on the drawings, the following steps should be taken.

Adequate means must be established to support the vessel to maintain shape and still allow for expansion and contraction.

To assure a minimum loss of material surfaces through oxidization, the atmosphere of the stress-relieving furnace should be subject to controls.

In addition to the atmosphere, adequate means must be established to check the actual temperature in the vessel proper. This is generally carried out by attaching thermo-couple leads to the inside surface of the pressure vessel.

To assure further control, the temperature of the furnace in the different zones, meaning the top and bottom, must be recorded and controlled to assure no overheating or too fast heating.

To eliminate the human equation, the recording gages for the temperature and rate of cooling should be connected to the heating controls.

FINAL TESTING

The final hydrostatic test is a check on all departments of the fabricating shop, as well as the engineering design. To carry this out properly, the following steps should be taken.

The vessel should be cleaned out and means taken to properly vent same before water is introduced.

Temperature of the water used in testing should be controlled, and held to a minimum of 68°.

Should other tests than a hydrostatic test be required, they succeed the hydrostatic test, which is generally carried on at a higher pressure, to assure safety in carrying out the tests.

Where air tests are required, more than one indicating or recording gage should be used, to assure that excessive air pressure is not set up in the vessel.

In all cases, the indicating gages should be checked against standards, and be used in addition to the recording gage when so stipulated.

To carry out vacuum tests with the least amount of time, all leaks should be located and corrected with a hydrostatic test. Location of same would be difficult to find on vacuum test.

Slight drop in vacuum test may result in changes in the weather, and if within 1% should not be considered serious.

PREPARATION FOR SHIPMENT

To assure the vessel's arriving at destination in such a manner as to eliminate back charges, the following points should be complied with.

To properly prepare for shipment depends on the end use of the vessel. The specifications must be followed and carried out to see that the surfaces are prepared as specified. If sandblasting of the interior surface is required, or grits blasting, the surface must be completely cleaned thereafter and surface inspected to be assured that no surface defects have been uncovered or exposed by the surface treatment.

If the exterior surface calls for painting, this must be applied to a dry surface, which is also free from dirt and foreign matter.

All gasket contact surfaces or highly machined surfaces should be protected with a heavy grease and wood or waterproof paper covers.

A complete list of parts to be shipped, either intact or loose, must be made and checked over by the Inspection Dept.

In placing the vessel on railroad cars or other means of shipping, as per clearance tolerances, a check must be made to see that all nozzles fall within the specified rectangular dimensions.

On extra long vessels loaded on more than one car, suitable bolsters must be designed to meet with railroad specifications, and these must afford means of tying the vessel down to said cars in such a manner that there will be no shifting enroute.

FINAL RELEASE TO RAILROAD OR TRUCKING

After all the above items have been checked, and the painted surfaces reinspected by the Inspection Dept., a written release should be issued to the railroad or carrier, and this should be signed for.

Welding Stainless Steel Containers to Meet Sanitary Standards

History of the development of high standards of sanitation in dairy equipment and various methods of joining metal to serve this industry

by P. H. Mounts

WELDING, as a process for fabricating stainless steel food containers, is basically the same as welding any other type of vessel. That is, the techniques used would fit the making of paper mill machinery, petroleum equipment or railroad cars. However, inherent in the food machinery business are certain details which affect the welding process greatly. These details are usually costly.

The principal detail is the fact that all these machines must be sanitary. That is to say they must not contain pockets or pits of even microscopic size which would act as harboring spots for disease breeding bacteria. Any and all defects which are visible to the naked eye are marked and eliminated by rewelding.

Sanitation in a dairy food container is not entirely a matter of pit free welding. In order to obtain a full degree of sanitation the machine must, first of all, be designed so the welds can be reached and ground and, secondly, must be designed so that cleaning the machine after usage is as easy as it can be.

It is interesting to note briefly how the dairy industry became so thoroughly conscious of sanitation and thus helped develop the machinery which we find today. It is safe to say, that in the quality of the finished surfaces there is no equipment built to higher standards. Figure 1 shows a machine which is typical of these standards. This is a vacuum pasteurizer which is used to remove "off" flavors from cream or ice cream mix. The stainless steel parts are joined entirely by welding. The only metal in contact with the cream during operation is stainless steel. Note that the design enables the machine to be quickly taken apart for cleaning. This is of importance to an operator when you consider that equipment must be dismantled, scrubbed and sterilized daily.

In addition to the history of the development of high standards of sanitation in the dairy industry, an explanation of the manner in which the Cherry-Burrell Corp. has progressed through the various methods of joining metal will serve to typify the dairy machinery industry. Due to the demanding nature of the fabrications the requirements for better more uniform methods of welding have kept this industry at the beginning of new developments in this field.

The dairy industry is built around one animal, the cow, a machine for producing milk—which we haven't yet been able to replace. The trouble with the cow is that she will not standardize. She may be large or small, may give milk with 6% butter fat or 3%, may be

Fig. 1 A vacuum pasteurizer showing the high degree of weld finish required. All chambers are welded construction

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healthy or diseased and this last fact is what forms the basis of our business. Diseased cows led to pasteurization which led to milk inspection which leads to the demand for better more sanitary machinery. This has paved the way to better welding to make the machinery more sanitary.

In the early days of milk production, the same man that kept the herd delivered the milk. He knew all of his customers and knew that the best way to lose his business completely was to let the rumor get started that someone had become sick from drinking his milk, that he had a sick cow. So these dairymen were very careful that their herds were healthy and drinking raw milk was not so dangerous as it later became.

As cities grew in size the demand came for mass distribution of milk in order to keep costs down. This built up the milk distributing companies which, of course, bought their milk from many different farmers and mixed it before bottling. If one farmer had a tubercular cow and was unscrupulous enough to sell the milk from this cow, he could infect thousands of people and still escape detection. Numerous outbreaks of typhoid fever, diphtheria, scarlet fever, dysentery and malta fever, have in the past been traced to raw milk. For these reasons cities passed ordinances requiring pasteurization of all milk. In order to enforce the ordinances the cities had to provide inspectors with authority to visit the dairies and check their methods of operation.

Pasteurization is a temperature-time relationship and in order to adequately inspect these processes the health authorities found it necessary to define the type of temperature measuring equipment which was acceptable. Then they progressed to telling the processor the desirable characteristics of the equipment that he used for the pasteurizing. As the sanitarians became more firmly established they extended their authority to all the machinery used in processing milk and its products and became the final authority in the design and use of these machines.

The sanitarians developed their ideas of what constitutes sanitary equipment independently and as a result there have been a lot of differences. In some cases there seems to have been a lively competition between sanitarians to determine which could set up the most severe requirements. As a result the standards of cleanliness and appearance rose very rapidly in this business. In trying to manufacture to only one standard for quality we have had to meet the requirements of the most demanding health inspectors. Otherwise we could not sell our products in the cities under their jurisdiction.

Figure 2 shows the inside of a modern creamery. This one is processing butter by a newly developed continuous process. Note the butter flowing down the slide into the machine at the left. The machines together with the gleaming walls and well-drained floors demonstrate the emphasis which is placed on sanitary equipment and surroundings. All the piping in this room which carries material going into the butter must be taken apart daily and thoroughly cleaned.

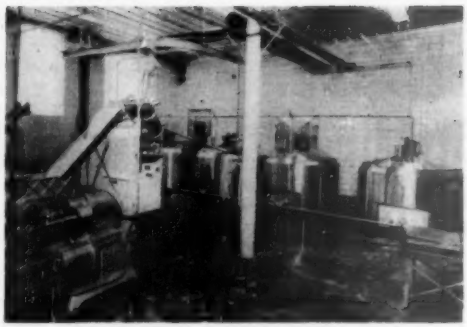


Fig. 2 A modern, sanitary butter plant

Attempts have been made in recent years to standardize the requirements on a nation-wide basis. States have written laws covering the minimum standards for all dairy processors, and the federal government through the United States Public Health Service has established and defined certain conditions of dairy sanitation which serve as a guide to individual health officers. In recent years an association of three of the most interested groups, the International Association of Milk Sanitarians, the United States Public Health Service and the Dairy Industry Committee has set down in black and white what is acceptable in each type of dairy machine, and this work has done much to settle the confusion. One question which caused a good deal of concern was the manner in which a weld in a sanitary vessel should be cleaned or finished in order to make it sanitary. The three associations mentioned above, settled this by deciding that the weld area should be the equal in appearance to the adjoining metal. This means that no defects are permitted in the welds and this fact has pushed the continuing search for better ways of making welds.

A look backward into the dairy machinery industry shows that the welding process developed rapidly because it has always offered a more sanitary method for joining metal.

The first joining method used was soldering. It came into use during the earliest days of the dairy machinery business before stainless steel was available. At that time copper, with a surface coat of tin was the only metal which would resist the attack of lactic acids and stand the daily scrubbings. It turned black in spots and the tin wore off exposing the copper and giving a coppery taste to the milk but that was the best there was.

These early milk processing vessels were fabricated by tinsmiths and joined by soldering. The corners which were sharp and would be difficult to clean were built up with generous fillets of solder. This arrangement suited its day and, incidentally, a rather extensive business was built up as a side line. This was the retinning of dairy machinery in the customers plant. A good many men who learned the trade in the factory set up their own businesses in this manner. As progress

in metals developed and sanitarians demanded the elimination of coppery flavor and unsanitary design the machinery manufacturers found better ways of designing to produce even better, more sanitary machinery. The most important single factor was the commercial development of stainless steel.

Stainless steel was first produced on a commercial basis in the late 1920's and the dairy industry was one of the first to use it. It seemed to provide the answer to all the objections raised about copper but unfortunately it was much more difficult to form and join than copper. The methods that were being used had to be pretty largely discarded and the newer techniques of welding substituted. This, ultimately, produced much better equipment; equipment which not only has more eye appeal because of its gleaming, flawless surfaces but which is functionally more efficient and economical.

One thing that the advent of stainless steel meant was that new ways of designing had to be found. Before, it had been enough to fill in a sharp corner with a large fillet of solder. Now solder was out and formed fillets and curves were used to fill up corners and smooth out the interior surfaces. One of the basic rules of designing food containers is that the weld should never be made in an internal corner. This is obvious if you consider the fact that these welds must all be ground and polished until they are practically indistinguishable from the surrounding metal. Think of the difficulties of grinding an internal corner weld. So the corner weld is out and the butt weld is the most satisfactory. Often extraordinary means must be taken to obtain this type of weld. Parts have to be flanged in dies or special fillets formed, but in this type of work these means have been found to reduce the cost of grinding and polishing so as to more than offset their cost. Figure 3 shows two types of weld that are typical of dairy machinery design. Note that the location of each weld is such that it makes grinding easy because the flat face of a standard round wheel can be applied. When special wheels such as mounted abrasive points have to be used to reach tight corners, the costs of grinding rise rapidly.

Earlier mention was made of the elimination of soldering after stainless steel became the basic material of the dairy machinery business. There are three reasons why soldering is not a good process for joining stainless steel:

1. It is difficult to flux the oxides off the stainless steel and thus difficult to get a good reliable bond.
2. It does not have enough mechanical strength.
3. The lead forms a black oxide after a short time in service and then its appearance is such a contrast to the gleaming stainless steel that it detracts from the appeal of the product.

As in most industries the first widely used method of welding in the dairy machinery business was the oxyacetylene torch. This method is so familiar that it does not need extensive coverage. In the hands of a skilled man it was, and still is, a very satisfactory method of joining stainless steel. Skilled men have always been a scarce commodity though and more foolproof methods were developed which supplanted gas welding. In addition to the skill required one of the disadvantages of gas welding on any but the lightest work is that it takes more time to bring the work up to welding temperature. This means that a wider area of the work gets heated through conductivity and leads to warpage which can be minimized with other welding processes. Another disadvantage due to this heating effect is that the stainless is held longer in the zone from 900 to 1400°. This increases the tendency toward intergranular corrosion due to carbide precipitation. These factors put gas welding out of the picture to be replaced, first by resistance welding and later by arc welding.

Resistance welding, that is spot and seam welding, has been used in this industry rather ingeniously to produce welds which can be economically ground. One of the initial limitations of resistance welding was the fact that the parts to be joined must be laid one on top of the other. That means lap welds. Figure 4 shows the difficulties inherent in grinding a lapped seam weld. The weld must be made as close as possible to the edge of the top sheet. Then grinding away the top sheet to produce a sound smooth surface can be held to a minimum. As shown, grinding will always produce the digging away of part of the thickness of the metal in the lower sheet. This is not good because it weakens the lower sheet. However, it is a fast way of joining stain-

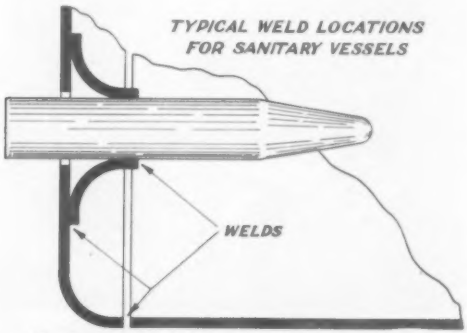


Fig. 3 Typical weld locations for sanitary vessels

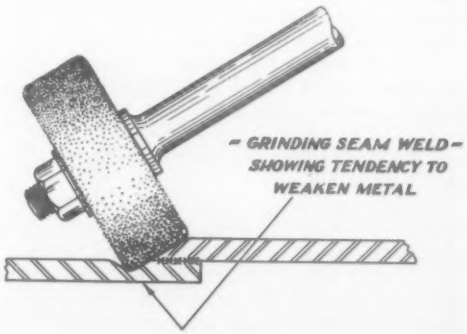


Figure 4

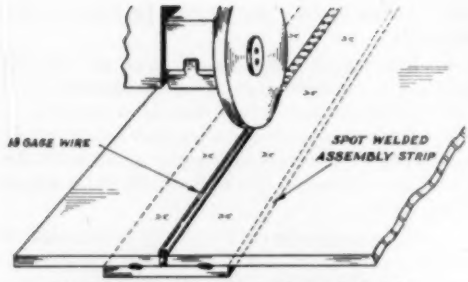


Fig. 5 Seam welding to produce a butt joint

less sheets and there is no rough heavy build up to grind away as in arc welding. With experience the rolls of the seam welder can be set up so that the top sheet of metal is pushed into the lower one while the metal is in the molten state. This reduces to a minimum the amount of step and reduces the amount of grinding required.

One rather interesting arrangement was devised to obtain a seam weld without the disadvantage of the overlapping of metals. Figure 5 shows a cross section of the arrangement. The two main sheets are to be joined in a long straight seam. First, they assembled by tacking a back-up strip in place with spot welds, at about 4 in. intervals. The 18 gage stainless steel wire is also spot welded in position at about 12 in. intervals. This assembly is then positioned in the seam welder resting on roller conveyor sections to enable it to be readily fed through. The seam welder rolls melt and join the wire to the edges of the main sheets resulting in a weld which is easily ground flush and proves to be quite sound in structure.

Spot welding is used principally to preassemble parts which are to be passed through the seam welder. It finds further usage in corners which are too small in radius to permit the seam welder roll to pass around. In these corners the spot welds are overlapped by hand positioning to make a continuous weld.

The resistance-welding process requires movement of the work, and as vessels became larger it is not practical to handle and move them for welding. In addition welding to minimize warping requires heavy fixtures and these do not adapt to the process. So as parts have become larger and fixtures more elaborate other processes of welding have entered the picture. Chief among them are metal-arc welding with coated wires and the inert-gas-shielded-arc welding process. The former of course has been basic for a good many years but the latter is rapidly replacing it wherever production or design is such that it will justify the expense of tooling for automatic welding.

It is interesting to note that the type of automatic metal-arc welder which uses a controlled feed wire and granular flux has never found a place in the welding of stainless steel sanitary vessels. The thickness of the metals used probably accounts for that. Stainless is an expensive material and so weight is kept to a minimum. Thicknesses of $^1/_8$ of an inch and less are most common. These are too light for this type of welding machine. Another disadvantage for sanitary welding is the fact that wire is always added to the weld. This means that a bead must be built up above the surface of the sheets welded. Even though this is kept to a minimum it is metal which must be ground away in producing sanitary vessels and this is not desirable from the cost standpoint.

The process which is making the most spectacular gains in the field of welding of stainless steel sanitary equipment is inert-gas-shielded-arc welding. Its use is largely confined to some form of automatic welding, that is, a setup in which machine movements control the weld progress.

When inert-arc welding was introduced for the fabrication of stainless steel it appeared to have the answer for most of our welding problems. It was readily adaptable to machine welding. It enabled the deposit of a bead of controlled height. There was practically no chance of inclusions in the weld. There was no spatter to clean up, and the heat-affected zone was narrow. The type of fixture we first built is shown in Fig. 6. It consists of two parallel beams of maximum rigidity which are spaced about $^5/_8$ of an inch apart at the narrowest point. The joint to be welded is centered in this gap and a copper back-up bar which is moved upward by a fire hose is brought against the lower side of the joint. The inert-arc torch is supported and fed by a standard unit designed for flame cutting. We applied this fixture to the job of inert-arc welding stainless-steel sheets in a butt joint without the application of any filler material. To illustrate the savings encountered: on one job we have to make a weld 8 ft. long in 16 gage 302 stainless. On this part the cost of polishing was $6.00. After conversion to inert-arc the weld cost $1.20 to polish. This saving could be realized because we eliminated several steps in the polishing process, that of cutting the weld bead down to the level of the

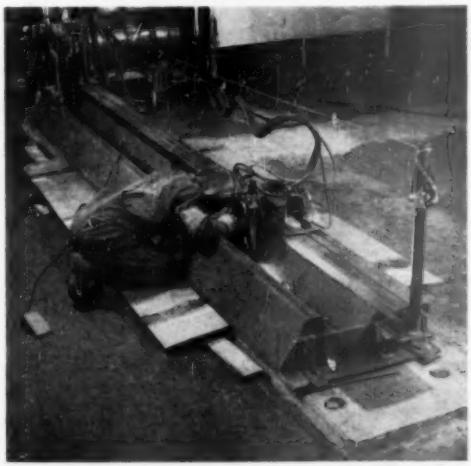
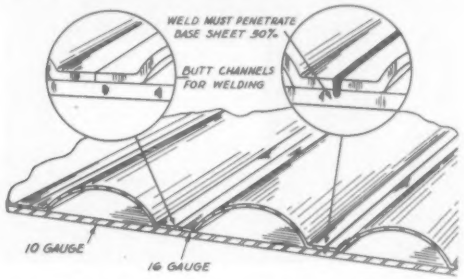


Fig. 6 Clamping fixture for inert-arc welding light stainless sheets

surrounding metal and the rough polishing of the weld area. With the inert-arc weld we are able to start the finishing procedure at a point nearer the final buffing operation. The cost of making the weld was less also because of the firm clamping and mechanical feed.

Inert-arc welding did not replace metal-arc welding completely in the sanitary equipment field. We found that two requirements had to be met before this new process could be economically applied. One, was that



METHOD OF ASSEMBLY OF AMMONIA CHANNELS
Figure 7

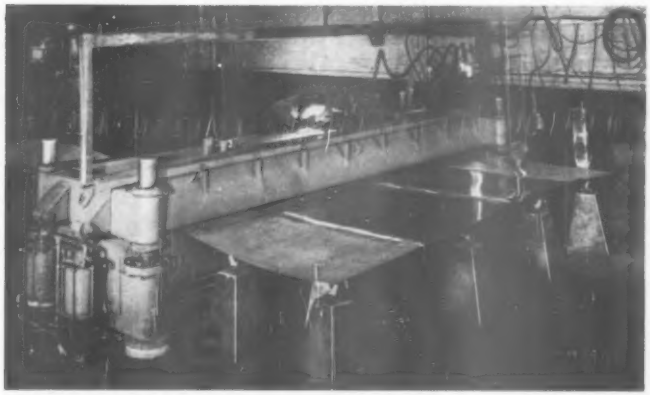


Fig. 8 Fixture for inert-arc welding ammonia channels shown in Figure 7

the parts had to fit together closely and two, that the parts had to be held in the proper relationship by substantial jigs and fixtures. We tried welding up parts with inert-arc without fixtures by first tacking them together and then welding off and we found that the advantages of inert welding were lost. The light tacks would melt when they were passed over in welding and the alignment of the parts was lost. Metal arc could do jobs of this sort well because the heavier tacks were not melted down enough to lose alignment. The skill involved in handling the inert-arc torch on this type of work was somewhat greater because the welder had to use both hands to add wire. These observations lead to the conclusion that the savings due to grinding did not offset the cost of fit-up and welding and so on the class of work which involves single units with no fixturing, metal arc is still the best method.

The foregoing conclusion has had a decided influence on the design of dairy equipment. In order to take advantage of the savings in polishing that the inert-arc welding process offers, we have gone to designs which utilize methods of manufacture usually found in the mass production industries. For instance, in order to obtain close fits and clamp the parts on fixtures we needed parts made which were identical. We installed hydraulic press equipment and made forming dies to obtain this end. Our runs are small usually not over 100 pieces but the gain in welding time and in polishing cost offsets the high cost of dies and setups.

Some of the setups we have made to properly position and hold parts for welding are shown in Figs. 7–10.

The Fig. 7 shows a design in which we are inert-arc welding rolled strips of stainless steel which have a shallow hat-shaped cross section, edge to edge on the back of a sheet of 10 gage stainless steel. Note that the weld is joining simultaneously both edges of the sections and the sheet beneath. This design allows the passage of ammonia around the wall of a cylindrical storage tank. These tanks are used for jobs such as lowering the temperature of milk after pasteurizing or maintaining ice cream mix at a low temperature prior to freezing.

Figure 8 shows the fixture which was developed to hold the parts for the refrigerated storage tank during automatic inert-arc welding. It incorporates certain features not normally found in a fixture of this type. The four cylinders at the end are lifters which through hydraulic pressure raise the top of the fixture up to 4 in. to permit location for welding or to give room to change the clamping bars. The clamping force is exerted through a bar of copper which rests on a fire hose. This has become a fairly common way of exerting pressure for this type of welding. In the completed part there can be as many as 80 welds 140 in. long and 2

Fig. 9 Horn fixture for welding cylinder

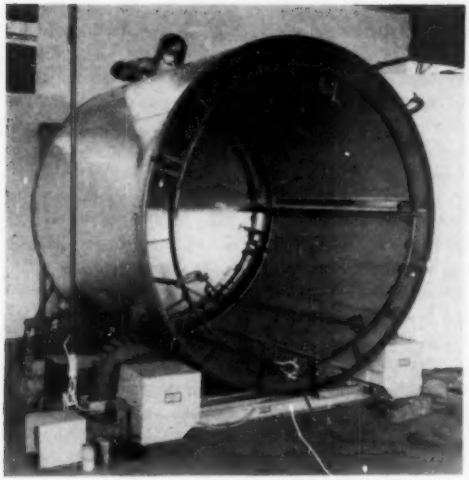


Fig. 10 Setup for welding dished stainless heads to sides

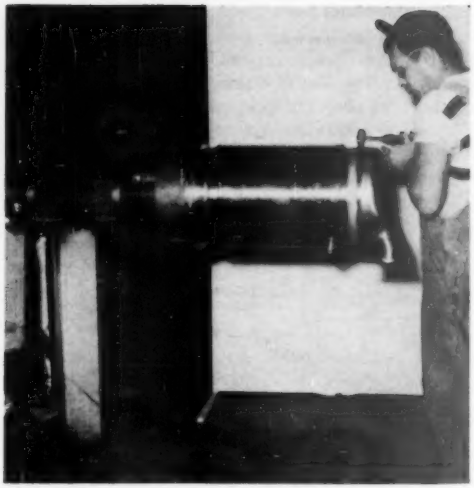


Fig. 11 "Cutting down" a weld bead. The first step in weld finishing

in. apart. Any attempt to apply such a large amount of welding heat to a sheet this size without the use of massive holding equipment would result in a warped and twisted mess so for this application such a fixture is essential.

Figure 9 shows a simple horn-type fixture on which we weld sheet stainless into cylinders. It will handle work from 9 in. in diameter up to 4 ft. or more. Note that the torch holding and driving mechanism is the same type shown in Fig. 6. This crawler can be picked up and carried from one fixture to another.

Figure 10 shows the setup developed for welding the heads into a milk storage tank. Note the expanding rings which fit inside the tank. These are faced with copper to carry away the welding heat. These rings had to be made so that they could be taken apart and removed through a manhole opening in the front head of the tank which is 16 by 20 in. in size. The entire tank is cradled in the caterpillar tread rotating positioner. The speed of rotation can be controlled by the welder. He holds the inert arc by hand and rotates the work beneath it.

We have other fixtures used to inert-arc weld certain parts but these illustrate that in a business where quality of finished product is the principal goal expensive equipment and techniques are economically justified.

Reference has been made several times to grinding and polishing process and some explanation is in order, since this is such an important phase and is tied up so intimately with the welding.

Figure 11 shows a man "cutting down" a weld bead with a "hard wheel." It is called this to distinguish it from the sewn canvas wheels and buffs which are used in subsequent steps of the polishing process. It is an ordinary 36 grit resinoid bonded wheel. In the next step an 80 grit "setup" wheel is used. This wheel is made of many canvas disks sewn tightly together to the circumference of which loose abrasive grains are fastened by gluing. The wheels are only good for from 15 min. to 1 hr. of work each so setting them up is done in the factory. After the 80 grit comes 120 and 180 grit, "setup" wheels which are the same except for the grain

Fig. 12 Buffing weld areas. The final step in weld finishing

size. The object is to remove the coarser scratches from the previous operations and more closely approach the scratch pattern produced on the sheets by automatic polishing machines. Final polishing involves buffs, which are loose muslin disks. These are used with very fine compounds applied from sticks which are held against the buffs while they are turning. Figure 12 shows a man buffing on a polishing lathe. This polishing procedure is lengthy and expensive and of course if defects are found in the weld the defect must be rewelded and the entire process of polishing repeated. This makes it imperative that sound welds be produced and is one of the principal reasons why the inert-arc process is in favor. It eliminates slag pockets and produces sound welds.

The welding of vessels to meet sanitary standards is governed by strict standards which were set up by individual health officers. The dairy machinery industry has always eagerly sought after new processes to enable these standards to be met at lower costs. Most recently the inert-arc welding process has been bringing the desired results. Proper application of this process has led to mass production techniques such as press forming, elaborate fixtures and automatic welding. This trend will continue to be the practice in the field of welding to meet sanitary standards.

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Sun Supertankers

A definite trend in tanker construction involves increased size, carrying capacity and speed

by A. A. Holzbaur and F. L. Pavlik

INTRODUCTION

THE "feast or famine" cycle of shipbuilding in the U.S.A. was in the latter phase during the greater part of 1947. With the announcement in the autumn of that year that Standard Oil Co. (N. J.) was contemplating construction of some supertankers there came a quickening of the tempo that snowballed into a major tanker shipbuilding program. At "Sun Ship" this was evidenced by the placement of contracts early in 1948 for thirteen tankers of the 26,000 to 27,000 tons deadweight class. Two of these were subsequently cancelled and the final list of orders included two ships for Standard Oil Co. (N. J.), two for the Kupan Transport Co. and seven for the Tankers Navigation Co., Inc. In a similar way improved shipbuilding conditions were manifested in other of the major shipbuilding yards on the eastern seaboard.

PRINCIPAL CHARACTERISTICS

The principal characteristics of these vessels were determined on the basis of complying with the following service conditions, viz:

1. Crude oil shipments from the Middle East to the east coast of the U.S.A., with adequate bunker capacity for the round trip.
2. Crude oil shipments from Aruba to the east coast of the U.S.A.
3. Gasoline shipments, etc., in the domestic trade from the Gulf ports to the east coast of the U.S.A.

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As a corollary to the above, the following conditions resulted:

1. The drafts could not exceed the maximum permitted for transiting the Suez Canal and also for docking at the U.S.A. terminus. (The Suez Canal authorities restrict normal drafts to 34 ft., although 35 ft. is permitted under special conditions.)
2. The capacity of the cargo tanks had to be adequate to accommodate the light gravity petroleums for a maximum cargo deadweight condition.

The Middle East Persian crudes have a gravity of 33° A.P.I. and consequently do not require, for the same deadweight tonnage, as much cargo tank space as gasoline, at 63° A.P.I. Accordingly, it was decided to use the aftermost wing cargo tanks as reserve tanks to augment the fuel supply of the main bunkers for round trip requirements of the Persian Gulf run.

Table 1 is a listing of the three groups of tankers built under this program, and gives the draft and deadweight data for each. Under the Load Line Rules the drafts assigned have been varied in accordance with the type of bridge construction.

The principal dimensions of the vessels were selected to provide a suitable, easy driving hull form, combined with qualities of sea kindliness, including comfortable rolling characteristics. These have already been demonstrated in service. The length/depth ratio of approximately 14 was selected to provide adequate longitudinal strength without incurring a penalty in the steel weight, and the depth was further influenced by requirements for an adequate cargo volume for light petroleum products, and to provide a freeboard in accordance with the Load Line Rules. Extensive longitudinal strength investigations were made for normal loading conditions for both gasoline and crude oil cargoes, and the resulting stresses in all cases were well within safe design limits.

Table 1

Company	*No. Ships*	*Designation*	*Bridge*	*Assigned drafts*	*Deadweight**
Standard Oil Co. (N. J.)	2	Esso class	Bridge Hse.	31 ft., 11½ in.	26,555
Kupan Transport Co.	2	Kupan class	Modified Br.	32 ft., 3¾ in.	26,878
Tankers Nav. Co., Inc.	7	Tankers class	Regular Br.	32 ft., 5 in.	27,003

* First vessel of each class.

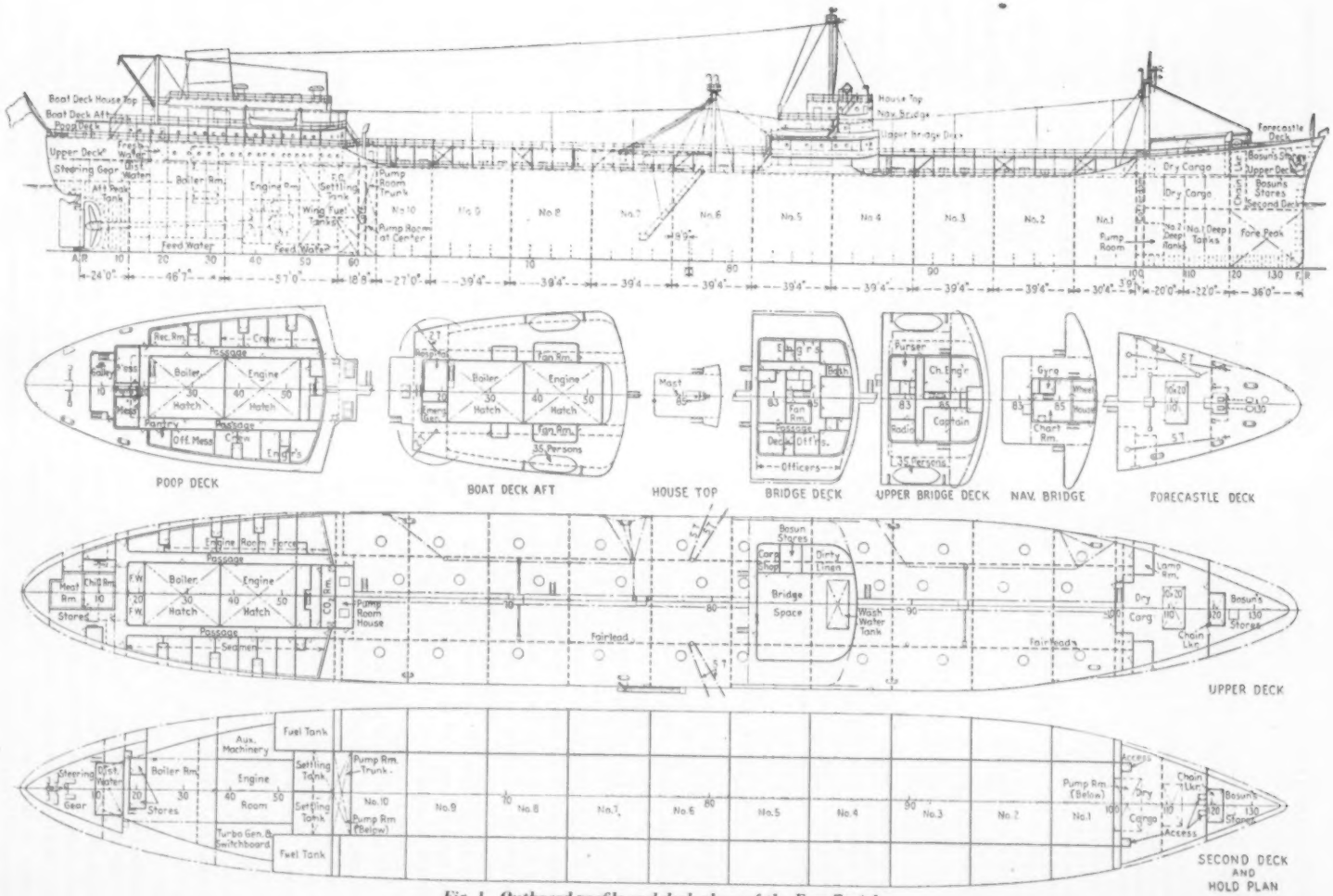

Fig. 1 Outboard profile and deck plans of the Esso Zurich

The principal dimensions and data generally pertaining to these vessels are presented below in Table 2.

Table 2—Esso Class

Length, overall		628 ft.
Length, between perpendiculars		600 ft.
Breadth, molded		82 ft., 6 in.
Depth, molded		42 ft., 6 in.
Design draft, molded		31 ft., 5 in.
Block coefficient		0.766
Cargo oil capacity, 100% full		230,997 bbl.
Dry cargo capacity, bale		53,160 cu. ft.
Fuel capacity, 100% full	18,203 bbl.	
Reserve fuel capacity, 100% full	9,232 bbl.	
Total Fuel	27,435 bbl.	
Fresh water, reserve feed		309 tons
Fresh water, distilled feed		97 tons
Fresh water, potable		71 tons
Tonnage, U. S. gross		17,647
U. S. net		10,885
Panama gross		18,129
Panama net		13,550
Suez gross		18,125
Suez net		13,990
Shaft horsepower, normal		12,500
Rpm., normal		112
Shaft horsepower, maximum		13,750
Rpm., maximum		115.7
Service speed		16 knots

GENERAL ARRANGEMENT

The general arrangement of the basic vessel is shown in Fig. 1. All vessels have been built with a curved raked stem, cruiser stern and single continuous steel deck. Forecastle and poop erections are common to all types with bridge construction varied as noted in Table 1. The vessels are propelled by a single screw, driven by geared turbines located aft in conventional tanker manner. The boilers, two in number, are located on a flat over the shaft alley space. The main cargo pump room is located at the aft end of the cargo oil space, and the cargo handling installations reflect the individual preferences of the owners as regards number and type of pumps and also piping arrangement. The normal pumping time for a full cargo varies from 8 to 12 hr., depending upon the pumping conditions.

The cargo oil space is divided transversely by two oiltight longitudinal bulkheads into a center tank and two wing tanks, and by transverse oiltight bulkheads into ten spaces longitudinally, making a total of thirty tanks. The total length of the tank space is 377 ft. 6 in. which corresponds to 62.9% of the 600-ft. length.

The bridge structure has accommodations for officers, recreation rooms, pantry and fan room, together with wheel house, chart room, gyro room and radio room. The poop accommodation houses officer, crew, recreation rooms, mess rooms, pantries, galleys, reefer and dry stores, CO_2 room, hospital, etc.

The vessels are rigged with king posts forward, amidships and aft, with radar mast stepped on the bridge structure. Booms forward, of 5 ton capacity, handle dry cargo and case goods; booms amidships handle the cargo oil hose; and booms aft handle miscellaneous stores, repair parts, lube oil in drums, etc. The "Esso" class of ships have been fitted with stores loading ports aft.

The vessels have been built to the highest class for bulk oil carriers in the American Bureau of Shipping, and the "Kupan" and "Tankers" ships are additionally classed with Lloyds Register. They are constructed in full compliance with the rules and regulations of the U. S. Coast Guard, Federal Communications Commission, U. S. Public Health Service and national, Panama and Suez Canal tonnage authorities.

STRUCTURAL ARRANGEMENT

The scantlings and arrangement of structural members are indicated on the Midship Section, Fig. 2. The framing of the hull is basically longitudinal except in way of the ends of the vessels where transverse framing is employed. The transition from longitudinal to transverse framing is effected through a suitable scarphing arrangement.

All welded construction is employed throughout except for such riveting in way of the oil space as follows: on each side of the vessel the upper and lower seams of the bilge strake, the lower sheer strake seam, the deck stringer angle and two deck seams. Additionally, on the "Tankers" class the seam of the flat keel to the garboard strake is riveted.

In way of the cargo oil space the intercostal transverse bulkheads are spaced 39 ft. 4 in. apart, and there are three transverse web frames per tank, resulting in a 9 ft. 10 in. spacing of webs. The continuous longitudinal bulkheads are located 20 ft. from the center line and terminate in deep brackets beyond the oil space.

The bulkhead construction is of the all-welded flat plate and stiffener type. To offset corrosion, the thickness of bulkhead plating at the top has been increased above rule requirements as follows:

Transverse bulkheads:
- Esso-Kupan class—Top strake increase = 0.06 in.
- Tankers class—Top strake increase = 0.18 in.
- Strake below, increase = 0.08 in.

Longitudinal bulkheads (Tankers class only)
- Top strake increase = 0.06 in.
- Strake below, increase = 0.08 in.

The brackets of bulkhead webs have a "soft toe" construction to prevent cracks in contiguous plating.

Transverse web frames have been arched to eliminate the tendency to form cracks in way of corner constructions.

The longitudinals are continuously welded and are through-bracketed at the transverse bulkheads.

The poop, bridge and forecastle erections, houses, flats, etc., are of welded steel construction; generally 8 ft. 6 in. high. The poop and bridge are framed transversely.

The welded steel fore and aft gangway is fitted with a walking surface of galvanized steel grating. The gangway is 8 ft. 6 in. high, extends between P.B. & F. erections, and is fitted with expansion joints at ends to allow for the working of the ship.

STRUCTURAL WELDING

The bow structure is a welded subassembly weighing about 30 tons. It includes a steel forefoot casting with stem plate above, first plate of all shell strakes and decks, breast hooks and stringers. It was built in a mocked-up horizontal cradle on the ground and erected as a unit on the shipway.

The stern frame is made up of three steel castings integrated with weldments at the lower and upper ends. The lower weldment connects the keel plates and the casting, and eliminates a large mass of casting at the bottom usually subject to shrinkage cracks, etc. The upper weldment effects a welded continuation of the shell plating and also contains the welded rudder trunk. The weight of this assembly is about 25 tons.

The rudder is of the balanced type with streamline cross section of double plate welded construction. Rudder castings are welded into the structure to take

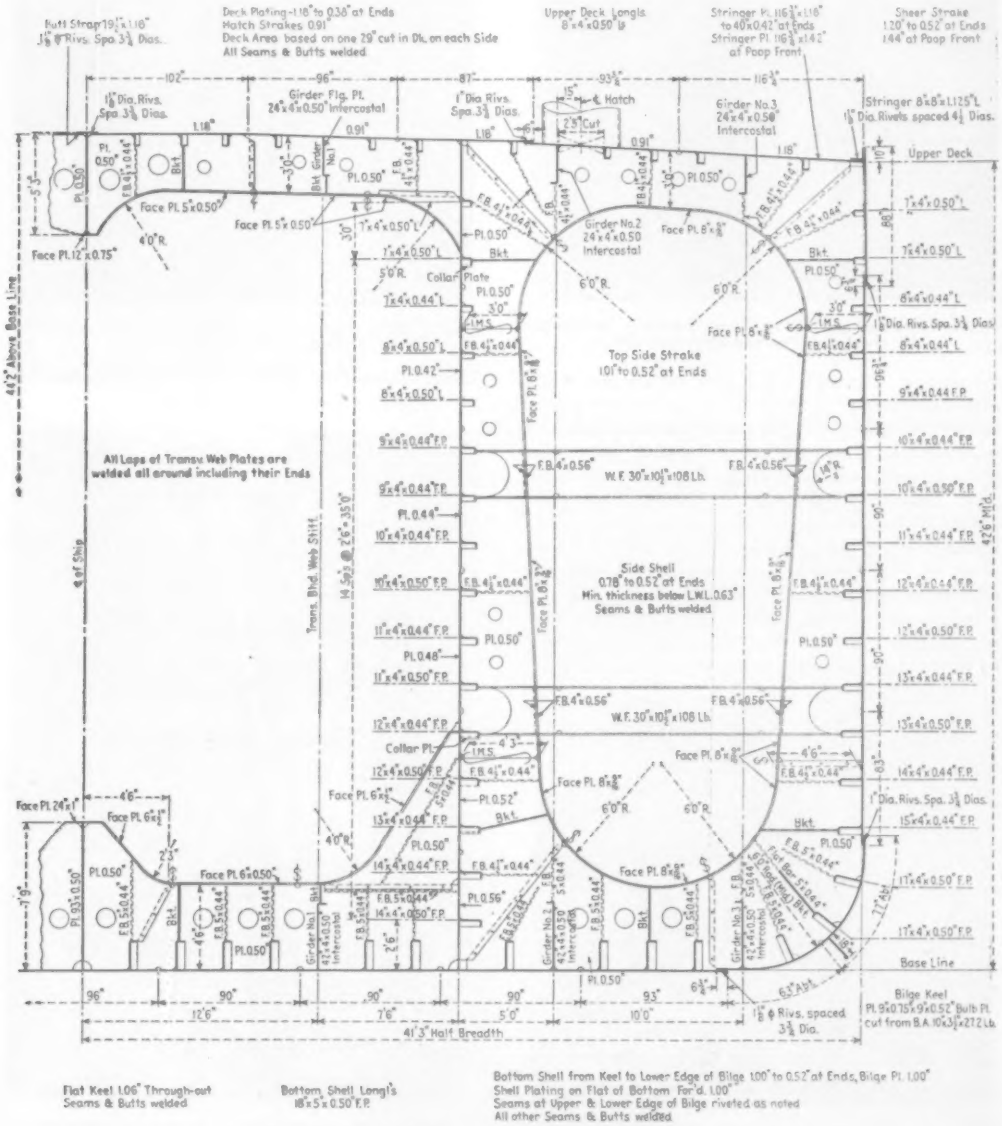
Upper Deck
Top Side Strake
Side Shell
Base Line
All Laps of Transv. Web Plates are welded all around including their Ends
Flat Keel 1.06" Through-out Seams & Butts welded
Bottom Shell Longl's
Bottom Shell from Keel to Lower Edge of Bilge 1.00" to 0.52" at Ends, Bilge Pl. 1.00"
Shell Plating on Flat of Bottom For'd. 1.00"
Seams at Upper & Lower Edge of Bilge riveted as noted
All other Seams & Butts welded
41'3" Half Breadth

Fig. 2 Midship section of tanker Esso Zurich

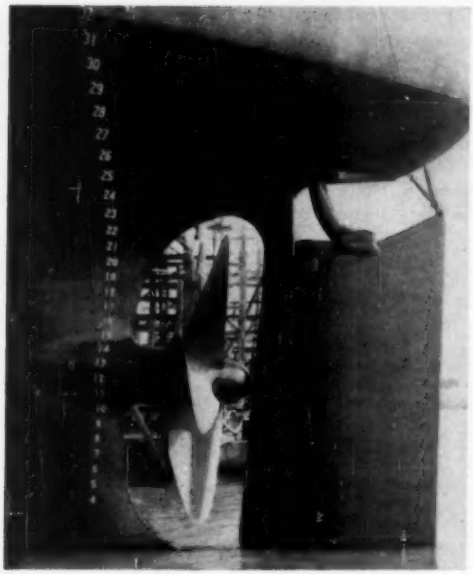

Fig. 3 Showing upper stern frame assembly, weldment for rudder carrier and welded rudder

the pintles. Figures 3 and 4 show stern frame, weldments and rudder.

The arrangement of shell plating permitted efficient use of shop automatic welding equipment. Subassemblies, generally one tank length long, were made for deck, shell and longitudinal bulkheads. Transverse bulkheads, both center and wing, were full size assembly units. Flanged plate stiffeners were fitted under a set of air jacks and tacked to individual plates. These were continuously fillet welded on tilting tables by the submerged arc process. These single plates, with stiffeners attached, were fitted, tacked and butt welded by the same process under a stationary welding machine.

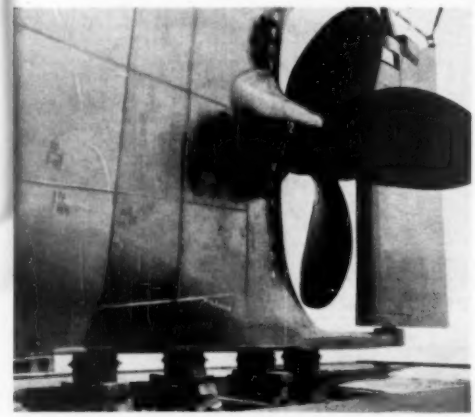

Fig. 4 Showing lower stern frame assembly and welded rudder

Fig. 5 Method of lining shell plates for welding—eliminating tack welds in butts

The web frames were cut, fitted and manually welded on an extension of the butt-welding table.

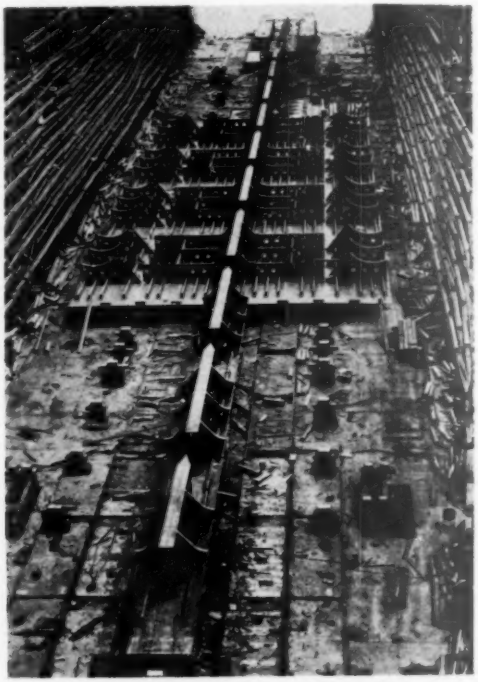

Fig. 6 Keel and shell bottom assemblies in place on shipway

Fig. 7 (Left) Longitudinal bulkheads and center section to transverse bulkheads erected on shell bottom

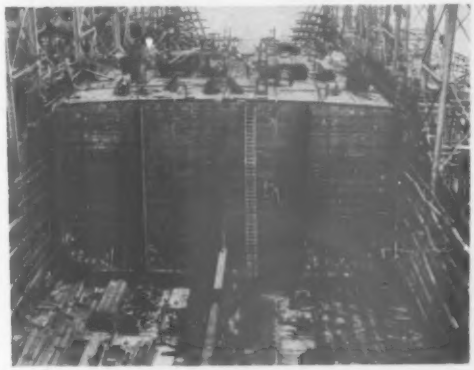

Fig. 8 Midship cross section erected, showing wing bulkheads, sideshell and upper deck

The films were examined by the X-ray inspection department and defects in welds detected thereby were removed, re-welded and re-gamma-rayed to prove acceptable. The Welding Engineering Department tabulated all exposures according to location and weld-

The pieces were removed from the welding table and turned over for back welding and final lofting and trimming. The pieces were cut to final dimension after all welding was completed and all shrinkage had taken place. They were beveled for single V butt joints.

These welded assemblies were erected on the ways and regulated with particular attention to the holding of proper root spacing of joints. They were aligned for welding by using pieces of $1^1/_4$- x $^1/_4$-in. flat bar as shown in Fig. 5. No tack welds were placed in the welding grooves.

The welding sequence had been laid out to follow erection closely in order to keep reaction stresses to a minimum and reduce the attendant difficulties with accumulated shrinkage. (See Figs. 6, 7, 8 and 9.)

As soon after welding as safety permitted the joints were gamma-rayed. Throughout the tank space every weld intersection was exposed and a sufficient number of random exposures taken to insure quality control.

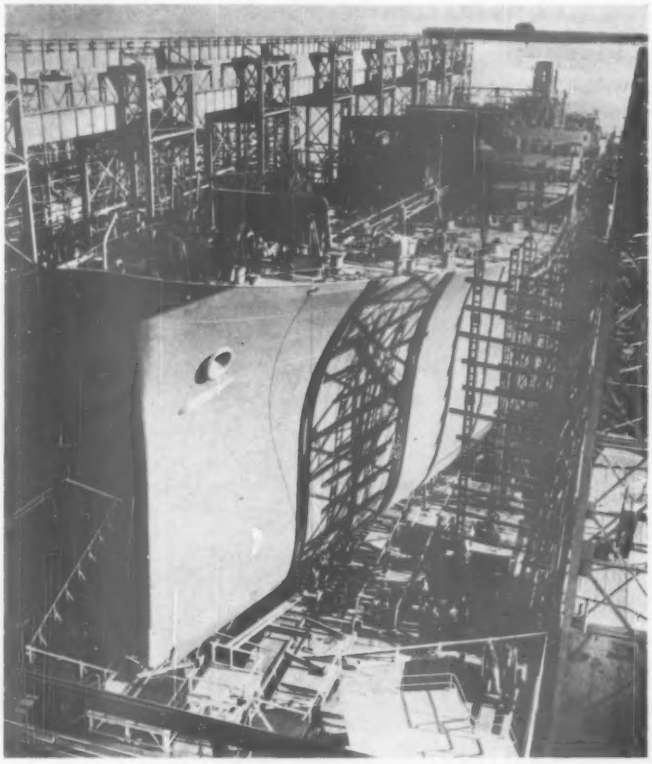

Fig. 9 (Right) S.S. Savac Daylight (Tanker class) just before launching

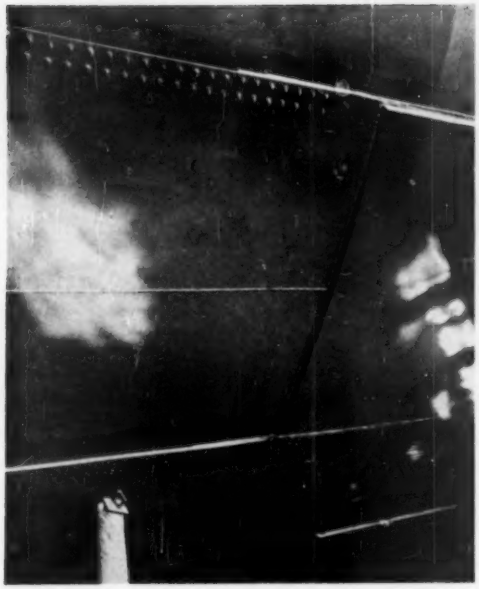

Fig. 10 Detail at ends of riveted seam

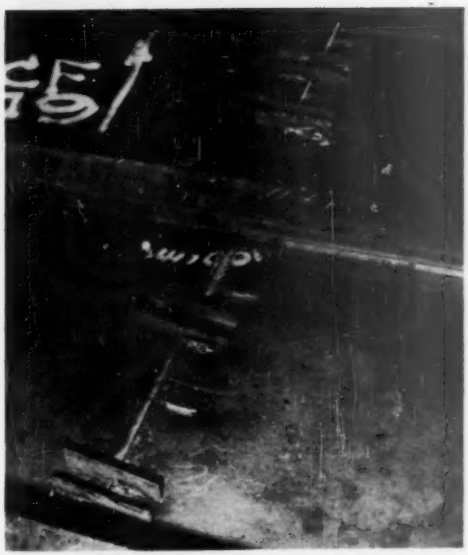

Fig. 12 Method of lining superstructure decks and bulkheads. Clips tacked on only one plate permit lateral movement

ing position. The completed welds in the cargo space, with the exception of the side shell verticals, were low-temperature stress relieved.

Welded butts of gunwale angle were backed up with strips of 18-gage black iron. These strips were left in and caulked tight. Inspection of several joints on the first few boats showed that the weld did not penetrate to the plate beneath. This was as required by the United States Coast Guard. The procedure was adopted in lieu of copper backing bars.

Beyond the cargo space at the end of the riveted seams, the transition to a welded seam was made by splitting the plate and fairing it in as shown in Fig. 10.

After the light superstructure bulkheads were erected, and before they were lined and tacked for welding, 3 x 12 wood ribbands were fitted as shown in Fig. 11. Special care was taken to see that all buckles were pulled out and that the bulkheads were absolutely fair. The tops and bottoms of these bulkheads were tacked in the conventional manner. The vertical

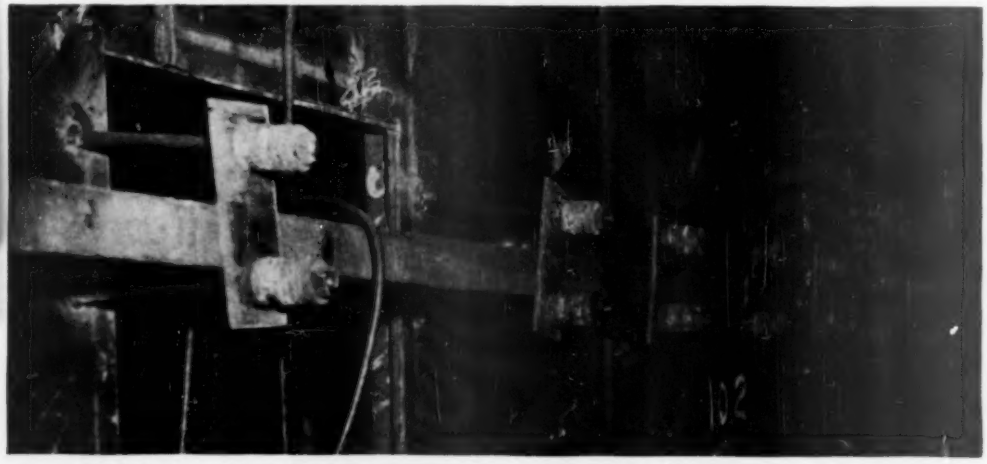

Fig. 11 Wood ribbands in place on superstructure bulkhead to avoid buckles due to erection, etc.

Fig. 13 "Flexible" strong backs used to allow shrinkage across butt welds of superstructure bulkheads

butts in bulkheads and the seams and butts of the superstructure decks were aligned as shown in Fig. 12 to permit slight movement. These butts were welded as the final operation. The resulting bulkheads were fair and true.

If, after removal of the ribbands, buckles or irregularities showed up, new slots were cut in way of the unfair sections and the butts thus made were welded to draw the material. These new butts were aligned as previously described. If strongbacks were required, they were installed as in Fig. 13 to permit slight movement during the welding operation. Spot shrinking, an expensive, messy operation, was practically eliminated.

On each of the supertankers there was about 600,000 ft. of welding. About 240,000 ft. was welded on the shipways. Automatic welding comprised about one-third of the shop footage.

PROPULSION MACHINERY

The propulsion machinery for these vessels consists of a set of cross-compound turbines, double-reduction geared; concentrating the power on a single screw shaft. This is in line with the recent practice for bulk carriers, and results in a greater efficiency of propulsion. The horsepower ratings have been tabulated in Table 1. The turbines for the Esso-Kupan class of ships were manufactured by the General Electric Co., and for the Tanker class by the De Laval Steam Turbine Co. The operating platform is located forward of the main turbine with gage board against the forward engine room bulkhead.

Steam for the turbines is generated by two Babcock and Wilcox, 2-drum boilers under the following conditions:

Esso-Kupan classes—Pressure 835 psig.; temp. 840° F.

Tankers class—Pressure 600 psig.; temp. 800° F.

The boilers have water-cooled walls, air encased front, superheater, internal desuperheater and four oil burners. The boilers operate under forced draft. They are seated on a steel deck over the shaft alley space, with an athwartship firing aisle on the forward end, and with a passageway between the boilers.

The Esso-Kupan classes have four stages of feed heating, whereas the Tankers class have two stages of feed heating, with an economizer in the boiler serving as the second stage.

The main and auxiliary condensers are of the Ingersoll-Rand, two-pass type and are designed to maintain a vacuum of 28.5 in. Hg. The condenser shell is of welded steel plate construction and is directly bolted to the low-pressure turbine exhaust flange.

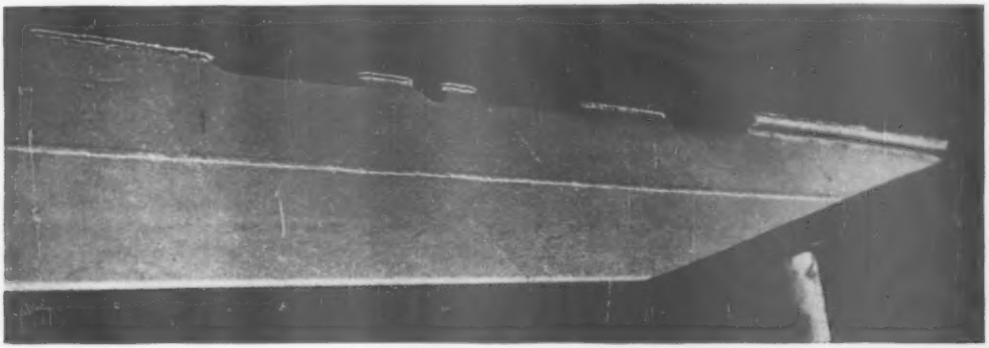

Fig. 14 Detail at end of bilge keel

A low steam pressure evaporating and distilling plant is fitted on each vessel.

Auxiliary power in the Esso-Kupan class of ships is generated as 60-cycle alternating current at 450 v. In the Tankers class the power supplied is 240 v. direct current.

Emergency power is supplied by a General Motors Diesel generating set in all ships.

The four-bladed, solid bronze propellers were made by the American Manganese Bronze Co., and are 20 ft. in diameter, 16-ft. 10-in. pitch.

CARGO SYSTEM AND DECK MACHINERY

As previously noted the cargo oil systems of the "Esso"-"Kupan" and Tankers classes of ships are dissimilar.

The Esso-Kupan ships are fitted with four Ingersoll-Rand, horizontal, centrifugal pumps; each driven at 1750 rpm. by a 450 hp. Whiton turbine, and pump at a rate of 4000 gpm. per unit. The turbines are located in the engine room abaft the forward engine room bulkhead and drive the pumps by shafts which pass through self-adjusting stuffing boxes and bearings in the bulkhead. The main cargo suction lines are 14 in. in diameter and are fitted with 12-in. discharges. The steam stripping pumps are a 700 gpm. Waterous horizontal rotary, and two 700 gpm. Worthington reciprocating pumps, duplex 14 x 14 x 12 in.

The "Tankers" ships are fitted with three Worthington, single-stage, centrifugal pumps each driven at 1750 rpm. by a 500 hp. Westinghouse turbine, and pump at a rate of 4060 gpm. per unit. The turbines are located in the forward part of the engine room and the pump drive shafts pass through stuffing boxes and bearings in the bulkhead. The main cargo suction lines are 16 in. in diameter with 12-in. branches to tanks and a 16-in. discharge line on deck. A 12-in. cargo line to the stern is also provided. The three steam stripping pumps are 500 gpm. National Transit rotary type driven by 75 hp. General Electric Co. d.-c. motors.

Weldments have been employed for sea chests, strainer boxes, etc.

Mechanical supply and exhaust ventilation has been provided for the pump room.

Access to each cargo tank is effected through a welded steel, 48-in. diameter cargo hatch, with 30-in. high coaming and Lukens Steel Co. dished head cover.

The dry cargo holds are served by 10 ft. by 20 ft. hatches; the weather deck hatchway is fitted with a welded steel watertight cover.

Steam driven windlass and winches, of American Engineering Co. manufacture, have been fitted. The windlass is 12- x 14-in. double cylinder, horizontal, triple spur gear reversing type with two cast steel wildcats and two gypsy heads. The two bower anchors are 15,500-lb. stockless type attached to $2^{11}/_{16}$-in. diameter chain.

The vessels are maneuvered by means of an American Engineering Co. hydroelectric steering gear with single opposed rams, Rapson slide and dual power units independently actuating the variable stroke, reversible discharge Hele-Shaw pumps. The ship may be steered from the wheel house, wheel house top, top of afterdeck house and steering gear space. A hydraulic telemotor system is provided.

ACCOMMODATIONS

The arrangement of accommodations for each class of ship reflects the individual ideas on the subject by each owner. The respective complements are:

Esso—58 officers and men, 4 passengers
Kupan—56 officers and men, 4 passengers
Tankers—80 officers and men, 0 passengers

The Esso class innovated an arrangement whereby both deck and engineer officers were berthed in the bridge house, with crew and messing facilities in the poop.

The Kupan class maintained deck officers amidships, with engineer officers, crew and messing facilities aft.

The Tankers class houses the deck officers in the bridge, with engineer officers and special crew accommodations in the poop.

Recreation rooms have been provided for officers and men.

Fireproof construction has been used throughout, for bulkheads, ceilings and linings; and metal furniture has been fitted. The deck covering in staterooms is Selbalith composition decking; ceramic tile is used in baths and toilet spaces and nonslip tile is laid in galley and pantries.

The accommodations are heated and ventilated by the "hot blast" system.

The reefer and dry stewards stores are located on the upper deck, aft.

EQUIPMENT

The vessels of all classes are equipped with radar, radio, radio-direction finder, gyro-compass, echo sounding device and automatic steering.

Life saving equipment includes four Maseco 24 ft., 40-person metallic lifeboats, one of which is a motor boat. The boats are stowed under Maseco mechanical boom type davits.

CONCLUSION

These vessels are representative of a definite trend in tanker design, not only in this country but also abroad. The trend in the U.S.A. is toward higher speeds and advanced steam conditions, and universally toward increased size and greater carrying capacity. The performance of these vessels will be observed with much interest.

Welding Aluminum with Inert Arc D.C.

Discussion by Glenn J. Gibson

It is very unusual and commendable for a welding method to be used in production without first going through the stage of laboratory development. Mr. Mortimer and the Whitlock Mfg. Co. have something to be proud of in this application of welding aluminum with the inert-arc d.-c. method. On the basis of a laboratory analysis and development of this method, there is nothing to criticize but much to add to Mr. Mortimer's presentation.

In the early application of the inert-arc method, the literature reports at least one application, where aluminum was welded with direct-current straight polarity.* In this application, helium was used with a flux; but this method was replaced by the a.-c. argon arc method without the use of flux. D.-c. welding with an argon shield, although possible, is very difficult and limited in application. The principal difference between the two gases being that the weld metal with helium flows much better and wets the edges producing smooth beads of concave contour. The beads produced with argon shielding with this d.-c. method tend to be rough and convex, and filler metal is not easily added to the weld. Weld penetration with argon is shallower and undercutting is more prevalent.

One of the principal advantages of this d.-c. method is the low cost and simplicity of the equipment required for welding. Any good d.-c. welding generator is satisfactory, and electrode holders do not have to be insulated for high frequency. This permits the very desirable factor of using unbreakable metal gas nozzles.

A significant improvement in this method has been obtained by the use of thoriated tungsten electrodes. These electrodes have a small percentage of thoria incorporated in the electrode by mixing with the powdered tungsten before they are sintered and drawn into electrode form. One effect of this thoria is to increase the current capacity because the thoria aids in the emission of electrons from the cathode and thoriated tungsten electrodes are therefore not required to get as hot as standard tungsten electrodes in order to provide the necessary emission. In fact, the end of the thoriated electrodes is not melted and retains its original shape. The arc striking is much easier and no tungsten spits off the end during this operation. The result is that the arc may be struck directly on the workpiece without resulting in tungsten inclusions in the weld. Conversely, accidental dipping of the electrode in the molten aluminum will not readily contaminate the electrode, and welding may proceed without stopping. The consumption of electrode is, therefore, much less than that of the pure tungsten type. The only disadvantage is that the arc voltage is from 3 to 5 v. less than that of a comparable arc with pure tungsten electrodes which results in somewhat less penetrating powers for a given current. This decrease in penetration is not proportional to the voltage difference because it occurs at the electrode and the heat liberated at this point is the least effective for welding.

The arc characteristics of this d.-c. straight polarity method of welding aluminum are best described from the photograph given in Fig. 1. This shows the manual welding of a bead on a $^{3}/_{4}$-in. plate with about 300 amp. current and with a $^{5}/_{32}$ in. diameter filler wire. The arc is similar to other d.-c. arcs in that it is very smooth and quiet, practically colorless, and providing deep narrow weld penetration. In the use of the standard a.-c. method of welding aluminum, the surface oxide film over the entire joint area is broken up and dissipated by the electrical action of the reverse polarity current. In the case of this d.-c. straight polarity method, the oxide film is broken to some extent as is indicated by the bright center of the weld bead shown in the photograph. The filler rod is always held in the weld pool, but it melts at some distance ahead of the arc and the

Fig. 1 Welding an aluminum bead with a helium shielded d.-c. straight polarity arc

Glenn J. Gibson is with the Air Reduction Laboratories, Murray Hill, N. J.

The paper by John W. Mortimer was published in the October 1950 WELDING JOURNAL, pp. 879–881.

* Leach, A. F., "Gas-Shielded Arc Welding of Aluminum," THE WELDING JOURNAL, 24 (12), 1129–1134 (1945).

Fig. 2 Macro of manual butt weld without backing in $^{1}/_{32}$ aluminum sheet

metal runs underneath this molten skin of the filler rod into the pool. There is no doubt that this method is effective in producing completely fused joints in spite of the absence of this electrical cleaning action. What probably happens is that when the edges are melted, the oxide film directly under the arc is broken and is attracted to the cooler parts of the fusion zone which is the edge of the upper surface of the weld. This layer of oxide film can be seen in this weld bead, but it can be readily removed by light-wire brushing, and the final appearance is equal to that produced by the a.-c. method.

The plate edge preparation found most suitable for this method is very simple. Closed square butt joints have been found to be the most suitable type up to $^{3}/_{8}$-in. thickness for both manual and automatic type applications. In manual welding, joints over $^{3}/_{8}$ in. should be beveled but left with from $^{1}/_{8}$- to $^{1}/_{4}$-in. square nose section, thus taking full advantage of the deep penetrating characteristics of the arc. When good fit-up is achieved, no root chipping of the weld is required to get X-ray sound weld deposits.

Another important advantage of this method over the a.-c. is that regardless of thickness, no preheat of the joint is required and welding may proceed practically immediately after the arc is struck. The question of cleanliness of the joint edges has not been fully investigated, but degreasing and wire brushing the edges prior to welding has been found satisfactory. Welds can be made over rather heavy surface oxide films but with greater difficulty and resulting in weld porosity.

The technique required for manual welding is very simple and surprisingly easy. The filler rod is always held in the puddle as shown in Fig. 1 and is melted down inch per inch of weld by the steady progression of

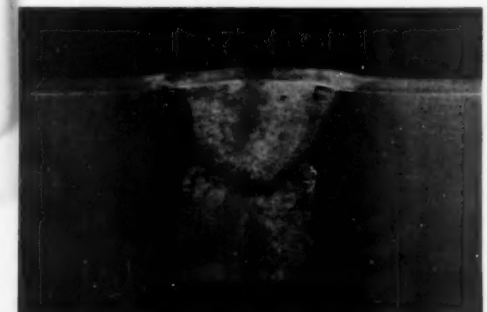

Fig. 3 Macro of a manual 2-pass butt joint in $^{1}/_{2}$-in. 61S aluminum plate

Fig. 4 Welding a horizontal position fillet in $^{1}/_{2}$-in. plate

the arc. The size of the weld is thus regulated by the size of the filler wire used. Some types of welds, particularly corner and flange joints can be made without filler or just by using a filler rod to start the weld. No unusual difficulties have been encountered in using these simple techniques; and as Mr. Mortimer stated, it is possible to do all joints with stringer bead technique

The range of application for manual butt welding is surprisingly large. Butt welds in $^{1}/_{32}$-in. aluminum can readily be made even without back-up under the joints. Such a weld is shown in Fig. 2. This weld was made with 20 amp. welding current at about 17 in. per minute with $^{3}/_{64}$-in. diameter filler wire. Figure 3 shows a macrosection of a $^{1}/_{2}$-in. manual butt weld made in two passes at a joint speed of 6 in. a minute. The edges of this joint were beveled $^{1}/_{4}$ in. deep and fit tight. The welding current required to achieve this remarkable penetration was 325 amp. The helium flow used for the $^{1}/_{32}$-in. weld was 10 cu. ft. an hour and only 20 cu. ft. an hour was required for the $^{1}/_{2}$-in. butt weld. Butt joints in 1-in. plate have been made without preheat and with only 5 passes.

Fillet welds can be readily made with this process. The technique required is very simple and is illustrated in Figure 4. A filler rod of the proper diameter to make the desired size of weld is held in the corner and the steady progression of the arc melts it and fuses it into the corner as a well-shaped fillet. A macrosection of

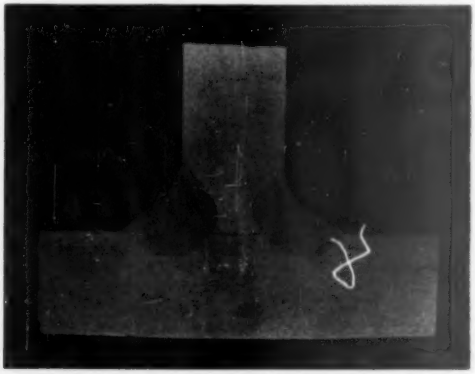

Fig. 5 Macro of $^{3}/_{16}$-in. horizontal fillet welds in $^{3}/_{8}$-in. plate

Fig. 6 Automatic welding a closed square butt joint in $^1/_4$-in. plate using automatic filler wire feed

$^3/_{16}$-in. fillet welds in $^3/_8$-in. plate is shown in Fig. 5. This illustrates the small size and the deep penetration achieved and also the desirable straight face fillets with concave "wet-in" edges. This weld was made using 330 amp., $^5/_{32}$-in. filler wire, and at a speed of 14 in. per minute. This d.-c. method permits the making of much smaller fillets than is possible with the a.-c. method. Horizontal fillet welds can be made in material from $^3/_{32}$ in. in thickness and up, and with fillet sizes ranging from $^3/_{32}$ to $^5/_{16}$ in. in one pass. Fillets can also be made in the vertical position in thicknesses of $^1/_4$ in. and greater.

This method of d.-c. welding is well suited for making joints automatically. A jig is used to clamp the edges and some back-up material is desirable. Closed square butt joints can be made in one pass up to $^3/_8$ in. in thickness, both with and without filler metal, although the use of filler metal is recommended for thicknesses greater than about $^1/_8$ in. Figure 6 shows a photograph of an arc with a machine holder and automatic wire feeder; and in this case, the wire is always $^1/_{16}$ in. in diameter and is fed at various rates depending on the thickness of the material. The wire melts off evenly at the edge of the molten pool as is shown in the photograph. The center of the weld produced is usually bright and shiny as shown, and the penetration is surprisingly deep in relation to the width of the weld. A macrosection of a closed square butt joint in $^3/_8$-in. plate is shown in Fig. 7. This represents what might be called the ideal in joint form. This joint was made with 430 amp. at 8 in. a minute and with a filler wire feed speed of 30 in. per minute, and helium flow of 20 cu. ft. an hour. The size of the thoriated tungsten used for this joint was $^1/_8$ in. and even at this current the end of the electrode remained square and unfused. The welding speeds for aluminum sheet are exceptionally high when compared to the a.-c. method. For example, $^1/_{32}$-in. aluminum can be welded at 300 in. a minute and $^1/_{16}$-in. aluminum at 175 in. a minute, both of these procedures are without filler wire. These welds were sound and developed the annealed strength of the material in a tensile test.

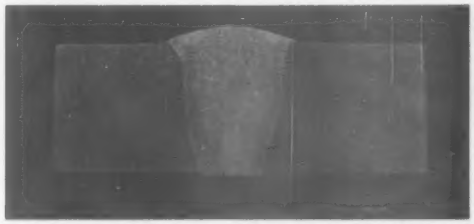

Fig. 7 Macro of an automatic one-pass butt joint in $^3/_8$-in. plate

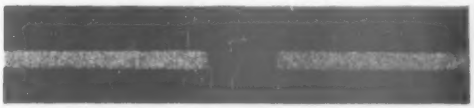

Fig. 8 Macro of a butt joint made at 300 in./min. in $^1/_{32}$-in. sheet

The mechanical properties of the welds made with this d.-c. method were determined from 17 manual joints and 14 automatic welds in thicknesses ranging from $^1/_{32}$- to 1-in. material. The average of 78 Transverse tensile test specimens are as follows:

Material	*As-welded, psi.*	*Heat-treated, psi.*
2S H14	13,500	
4S H34	27,000	
61S T6	31,000	45,000

These as-welded tensile properties are somewhat higher than the "O" temper strength of the 2S and 4S alloys and the values for 61S material are equal to the T4 condition. The heat-treated tensile properties of the 61S specimens meet T6 temper properties of the plate material even in the $^3/_4$ in. thickness. This remarkable effect is the result of the small proportion of filler metal relative to the fused area of the joint, and to the relatively small heat input to the joint. Another desirable feature of welds made with less heat input is less shrinkage and distortion of weldments.

Root and face band tests were made on all the joints tested and although there are no standards to evaluate such tests, they all showed comparable ductility to similar joints made with other methods. Some free-bend ductility tests showed about 20% elongation on 61S T welded joints and 35% on 2S and 3S welded joints.

SUMMARY

Mr. Mortimer has pointed out the advantages of low equipment cost, lower gas cost and no radio interference. The other desirable features of this method of

d.-c. aluminum welding developed by laboratory investigations are:

1. The improvements resulting in the use of thoriated tungsten.

2. The remarkable speeds and welds obtained by automatic or machine welding.

3. The broad range of thicknesses for which this method is applicable.

Crack Sensitivity in Aircraft Steels

Discussion by C. E. Sims

This comprehensive and carefully conducted investigation seems amply to confirm the very important part that hydrogen plays in the cold cracking of weldments. In addition, it gives practical suggestions for ways in which cracking may be avoided. That these means of preventing cracking are compatible with the known behavior of hydrogen in steel seems fairly obvious. It is highly desirable, therefore, that we have as clear an understanding of the basic principles involved as possible, in order to apply them to the problem of obtaining sound welds.

On page 757, under the subject of the "Effect of Postheat Time Upon Crack Sensitivity," it is shown that a postheat time of 20 min. at 600° F. is sufficient to prevent cracking, even in 4330 steel, which is the most crack-sensitive of the low-alloy steels tested. It is implied that cracking was prevented because of the elimination of hydrogen.

There is no reason to doubt that the elimination of hydrogen to some low content would prevent cracking at room temperature, but there is reason to doubt that sufficient hydrogen could be removed to accomplish this result in 20 min., even at 600° F. Mallett and Rieppel* have obtained strong supporting evidence that cracking of this type occurs during the delayed transformation of retained austenite (often isothermally at room temperature) in the presence of some minimum quantity of hydrogen. The decomposition of temporarily retained austenite in the absence of hydrogen, or the presence of hydrogen without retained austenite that will break down, does not produce cold cracking.

Examination of the S-curve data for a 4330 steel shows clearly that 600° F. is the most favorable temperature for the rapid, complete decomposition of austenite. It is virtually completed in 15 to 20 min. at this temperature. At either 500 or 700° F., it would take about five times as long. Thus, there is good reason to believe that a successful postheat treatment prevents cracking by transforming the retained austenite at the postheat temperature.

This is more vividly shown in the case of the Type 410 hardenable stainless steel, as described on page 763. Postheat treatments of 500 and 700° F. did not prevent cracking, whereas heating at 600° F. did. This occurred despite the fact that 700° F. should be more favorable to hydrogen elimination than any lower temperature. This portion of the S-curve for a Type 410 steel was not available, but high-chromium hardenable steels all seem to have similar S-curves, with the curve for complete transformation swinging sharply to the left and then reversing with the left-most apex at about 600° F. Stainless Type 410 is a more sluggish steel than 4330 and requires a longer time even at 600° F. than does the latter for complete decomposition of austenite. The times required at 500 and 700° F. would be proportionally still longer.

When hydrogen is present along with retained austenite, it concentrates highly in the latter because of its greater solubility. When the small austenite islands transform at room temperature, the hydrogen is released locally, and, because it cannot diffuse away fast enough, it generates aerostatic pressures great enough to produce small ruptures in the steel. The rate of diffusion of hydrogen at 400° F. has been estimated to be 240 times as fast as at room temperature,† and when retained austenite transforms to release hydrogen at this temperature, it diffuses away too fast to build up disruptive pressures. At 600° F., the diffusion rate would probably be 500 times as fast as at room temperature.

If enough austenite is retained which does not transform at room temperature, it acts as a reservoir to hold the hydrogen in solid solution where it does no harm. This is notably evident when austenitic stainless steels are used as filler rods, for they quite effectively prevent cold cracks in the presence of hydrogen.

Support can be given to the authors' opinion that vanadium decreases the crack sensitivity by forming stable carbides which are but slowly soluble in austenite. In one of the papers mentioned (Reference No. 2), it was shown that spheroidization treatments lowered the crack sensitivity of 4130 steels. It was thought at that time that the greater size and lower surface energy of the spheroidized carbides was responsible. Since

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C. E. Sims is Assistant Director, Battelle Memorial Institute, Columbus Ohio.

Paper by A. W. Steinberger, B. J. DeSimone and J. Stoop was published in the September 1950 issue of THE WELDING JOURNAL.

* Mallett, M. W., and Rieppel, P. J., "Underbead Cracking of Weldments Cathodically Charged With Hydrogen," the *Welding Research Supplement*, July 1950.

† Sims, C. E., Moore, G. A. and Williams, D. W.: "The Effect of Hydrogen on the Ductility of Cast Steels," AIME Metals Technology, February 1949, T.P. 2464.

then, extraction and analysis of the carbides has shown that spheroidization treatments increase the quantity of chromium and molybdenum carbides at the expense of iron carbide and makes the carbides much less readily soluble.

Authors' Reply

The authors thank Mr. Sims for his discussion of this paper. Because Mr. Sims is both a pioneer and a recognized authority on the subject, his comments are of particular value.

It was not the authors intention to imply that the absence of cracking in the specimens postheated for 20 min. at 600° F. was due exclusively to the elimination of hydrogen. While the greater portion of the hydrogen is evidently eliminated by this treatment, there is undoubtedly a certain amount remaining. It is hoped that future work will enable quantitative evaluation of the residual hydrogen under the various conditions outlined in the paper.

On page 753, Paragraph 7, the authors implied that "transformation must be promoted at a temperature sufficiently elevated that the dissolved hydrogen can escape without building up high aerostatic pressures." The vital role of austenite transformation is also mentioned in other parts of the paper.

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Backhand Welding of Pipe

By J. W. Carrier

MOST of the welding instructions given are usually for the forehand welding method. That's because for most jobs forehand welding is the recommended method. It is easy to do and one needs only a little practice before a satisfactory weld can be made.

For fast efficient pipe welding, the backhand method is recommended. In the backhand method an excess acetylene flame is used. The welding flame is directed backward at the completed weld. Welding progresses from left to right (for a right-handed operator) and the welding rod is between the complete portion and the flame.

J. W. Carrier, The Linde Air Products Co., Indianapolis, Ind.

ADVANTAGES OF BACKHAND METHOD

With this positioning of the flame and rod, the flame can be directed at all times on the edges of the vee

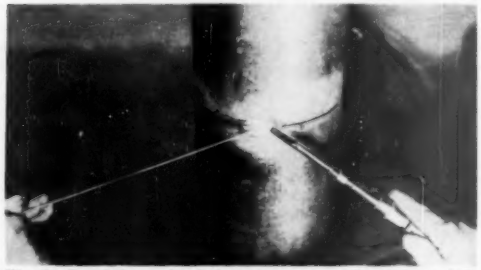


Fig. 1 Bevel the ends of the pipe to an angle of about 35°. Leave a space approximately the diameter of your welding rod between the pipe. Make three tack welds

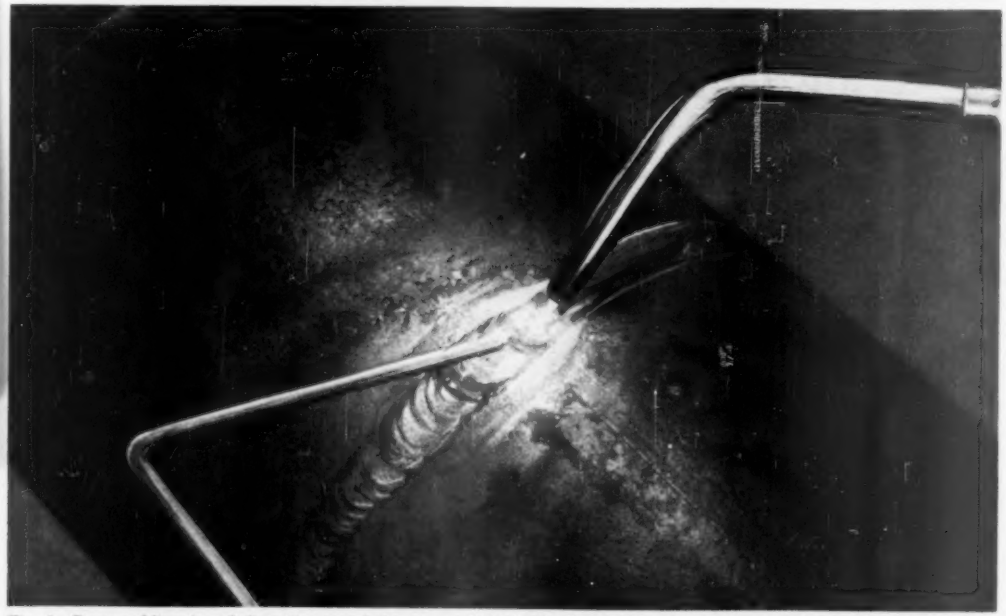


Fig. 2 Start welding just below the top of the pipe. Melt both edges of the pipe to form a puddle. At the same time heat up the welding rod in the flame

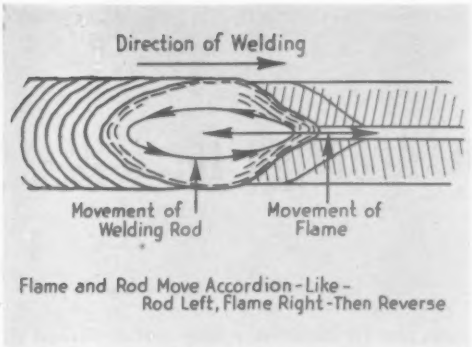

Direction of Welding
Movement of Welding Rod
Movement of Flame
Flame and Rod Move Accordion-Like-
Rod Left, Flame Right-Then Reverse

Fig. 3 Add molten weld metal and when the puddle fills the vee, start the movement of the welding rod and the flame, as shown here. This is an accordian-like motion

Fig. 4 As welding proceeds, rotate the pipe so that the puddle is always just below the top of the pipe as shown here

ahead of the puddle without moving the blowpipe and rod from side to side. This gives the following advantages:

1. The flame can be concentrated mainly on the melting of the rod.

2. A more plastic, less fluid puddle can be used. This means that less heat is required.

3. Welding speeds are increased two to four times and consumption of rod and gases reduced 25 to 50%.

These photographs show how to do backhand welding. However, practice will be required to obtain complete fusion between the weld puddle and the edges of the pipe.

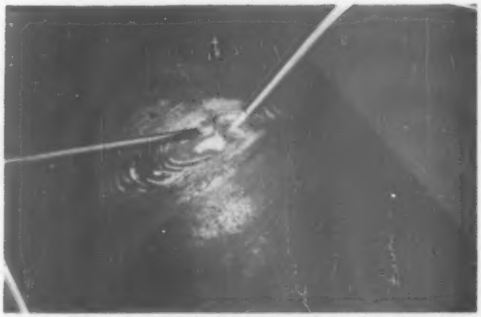


Fig. 5 When you reach the end of the weld, slow down welding until the entire surface of the start of the weld has been melted. Then build up the weld to full size

Fig. 6 To make a horizontal backhand weld, the rod should be held either horizontal or at an angle between horizontal and vertical. Point the flame straight into the vee or slightly downward

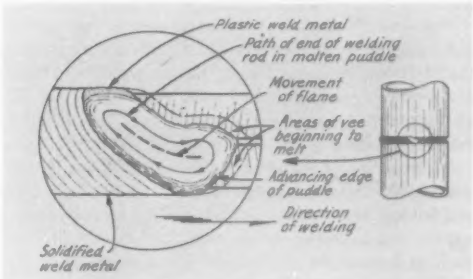

Plastic weld metal
Path of end of welding rod in molten puddle
Movement of flame
Areas of vee beginning to melt
Advancing edge of puddle
Direction of welding
Solidified weld metal

Fig. 7 As shown here, weld metal is built up along the lower side of the vee a little distance in advance of the upper side. This provides a shelf or ledge that supports the puddle

Economies Accomplished by Redesign for Welding

Several jobs are selected to illustrate the conservation of materials and reduction of manufacturing costs and how they can be brought about by redesign for welding

by K. H. Jackson

I CAN recall a few years back, the general topic of conversation among industrialists was, "I would certainly like to reduce the costs of our product," and they were quite sincere about it. But now the phrase is, "the necessity of reducing costs." Each manufacturer has his particular reasons, but, I think, the most pertinent ones are:

1. Competition, which has been the driving force of our industrial setup and has made the United States the great country that it is. My prayer is "may competition always be with us."

2. The ever-increasing cost of labor. It must be remembered that if our plant were destroyed to the last machine, but our people left intact, we could eventually get back into production because our people have the "know-how." But, if it were the reverse, the people gone and the machines left intact, the answer is obvious. Therefore, the spiraling labor demands must be synchronized with manufacturing cost reduction or all of our efforts toward higher standards of living will go into reverse such as the well-known "thirties."

3. Scarcity of materials. The demand for materials through the war and the race of reconversion was so sudden and heavy that raw and basic materials' producers did not have the facilities to provide, but they are making determined efforts toward improvement.

With these factors confronting us, it is more important than ever, with the world situation as it is, that we redesign for the conservation of materials and reduction of manufacturing costs. A product must be reviewed with the following factors given serious consideration:

1. Quality.
2. Product function or operating characteristics.
3. The means of servicing.
4. The availability of material selected for the potential redesigned unit or product.
5. The monthly production schedule.

The first three factors listed above should be improved if at all possible and under no conditions should they be reduced due to a desire for redesign only.

The production schedule will have a distinct determining factor upon what floor space can be economically allocated to the process.

In selecting a process, taking into consideration there is a choice by the nature of design, the quality and manufacturing tolerance should be given first consideration—then comes the monthly production requirements.

The existing machine tools and welding equipment should be analyzed for available man hours and any new equipment should be purchased with versatility in mind.

I have selected a few jobs for display that are rather simple individually, but are quite impressive when viewing the savings that their redesign effected.

The cast steel bracket on the right of Fig. 1 was the original design. It was quite heavy and it was necessary to mill the two faces as well as drill and backface nine $^1/_2$-in. holes.

The original design of the redesigned bracket called for a plate to be punched and then bent to a right angle. The two supporting members or gussets were to be flame cut and then welded to the plate inside and on the outside which summed up to approximately 42 in. of weld. The savings under those conditions would have been approximately 25%. We studied our production requirements and it was apparent that we could blank and pierce for the first operation, form on the second operation and then weld the corners. The redesign in Fig. 1 affected a savings of 152% over the original cost design.

The two angles, sheared plate and two reinforcement bars are the piece parts that make up a tractor main frame, shown in Fig. 2, that is assembled and tacked ready to be machine welded. Please note that on this

K. H. Jackson is with the Caterpillar Tractor Co., Peoria, Ill.

Presented at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

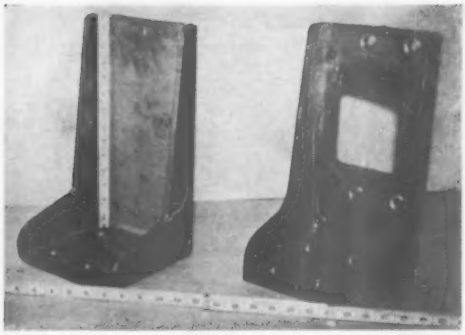


Figure 1

Figure 2

design it is necessary to weld six seams.

Figure 3 shows a new design using two special rolled sections and a sheared plate. The piece parts are assembled in a holding fixture, which eliminates tacking and the two seams are then welded at a speed of 15 in. per minute using the Union Melt process. We get

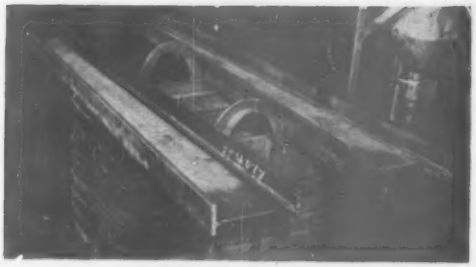


Figure 3

100% penetration by using a copper back-up bar. The welded assembly in Fig. 3 shows this penetration as it is the back view.

Figure 4 shows a cast steel idler.

Figure 5 shows the new design of the idler. Tests under rigid operating conditions show that the new design is superior to the old design due to special rolled section used in the rim. The rim is rolled and then butt welded.

The plates are blanked and the hub that receives the bearing is tubing. The piece parts are assembled and tacked and then Union Melt welded. We have the same machining operations to perform as on the original

Figure 6

design, but we have a reduction in weight, better operating conditions and a remarkable saving in material.

The savings in manufacturing is 23% but the effect of the new design to operators and owners cannot be measured dollarwise.

The casting on the right hand side of Fig. 6 is milled on the two faces, drilled and backfaced. When considering making it into a weldment the standard angle was acceptable, but the two gussets were deemed necessary; this resulted in actually a copy of the existing piece part. Even under those conditions by being able to punch the holes and eliminate the milling, we were able to save 27%. Later tests were conducted which substantiated the fact that gussets were not needed and this increased the savings to a total of 49%.

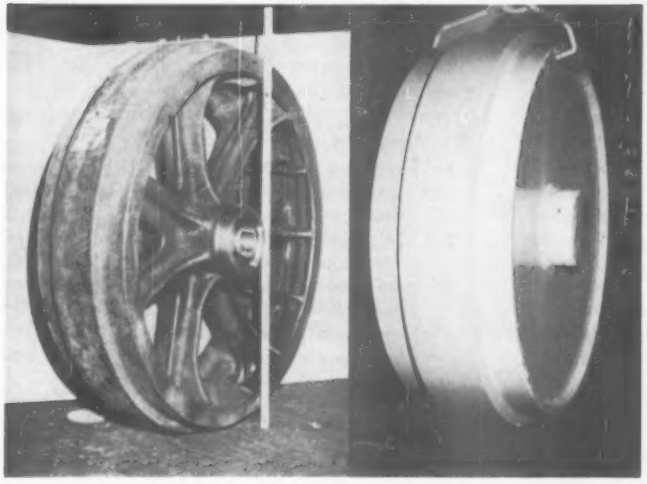


Figure 4

Figure 5

Figure 7

Figure 7 is a cast steel and weighs 49 lb. The long cored hole must be straddled, milled and bored. Actually there are two diameters in the bore, one about 0.010 smaller than the other so that we do not have to press the pin the full length. The other cored hole must be bored, counterbored, faced and backfaced. Bronze bearing must be pressed in and then finished bored. The pin must be centered, and drilled the full length, turned and then ground. The pin is then pressed in.

Figure 8

Figure 8 shows the redesign. The tube is cut to length, the two forgings are butted up in a fixture and welded. This subassembly is then milled to length and centered. The forgings are then faced and turned. The lubricating hole is drilled in the center. The other end is made from hot rolled bar stock. It is cut to length, drilled and counterbored to the rough dimensions. The subassembly, two side plates, gusset and bearing retainer are then assembled and welded. A finish bore is then taken on the bearing retainer, a bronze bushing pressed in and then reamed. This

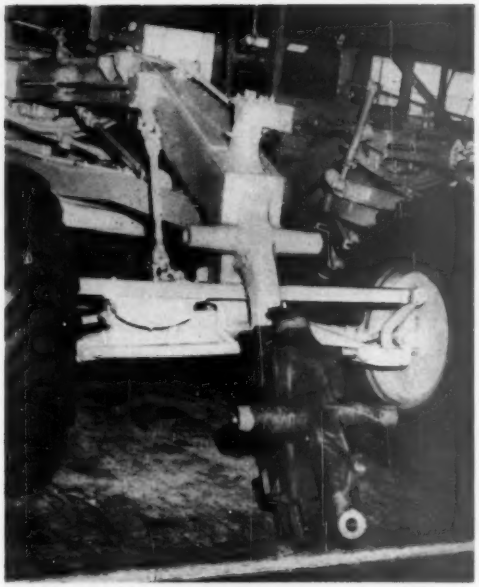


Figure 9

method of manufacturing made possible a savings of 36% as well as reducing the weight of the unit.

Figure 9 is shown only for comparison. We studied the possibility of redesign. First of all the weight is desirable in the front end. All of the machining must be held to a close manufacturing tolerance. So we would have the same machining operations to perform plus the welding, we decided to retain the present design.

In conclusion we may ask the question how are we to assure ourselves of a future in economical manufacturing procedures. That is best answered by selling the young design engineer the idea of his important role in manufacturing economy.

The welding industry should make available to the young man of mechanical enginering background or its equivalent the following experiences before putting him on creative work.

1. Experience in the shop where he may acquire the fundamentals of machining and the potential economies of the press shop.
2. The various welding and cutting processes and their applications.
3. Some time with an erecting or service engineer to see first hand the assembly problems due to design and, of course, failures due to faulty designs or miscalculation of torque, impact, tensile, etc.

Prolonging Tungsten Electrode Life

Longer electrode life, better welds, labor saving, lower welding costs will result from following these simple instructions given by Fansteel Metallurgical Corp., North Chicago, Ill.

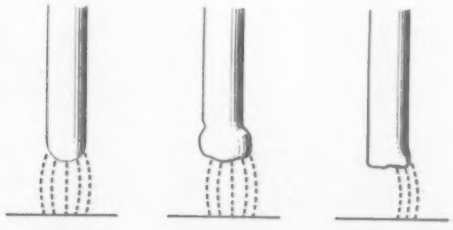
TUNGSTEN is a valuable metal, and tungsten electrodes should be cared for and conserved. Even more valuable is welders' time, and the prevention of spoiled work. By following these simple instructions, you will avoid waste of tungsten electrodes, you will save time and obtain better, cleaner welds.

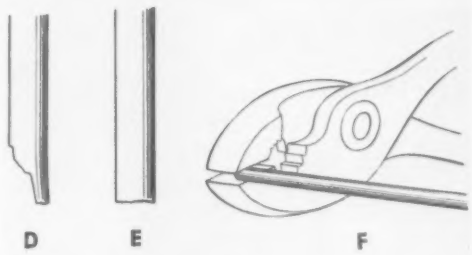
1. Keep tungsten electrodes clean. They are thoroughly cleaned at the factory before shipment. Dirt, grease or oil on the electrodes contaminates your welds. Do not let tungsten electrodes lay around on the bench. Keep them in their original package until you use them.

2. Use the correct electrode diameter for your current setting. When current density and electrode diameter are right, the electrode forms a spherical end (see drawing *A*). Too much current causes a molten misshapen blob which may drop off into the weld (*B*). Too little current (or too large an electrode) causes a wandering arc (*C*). Remember—more current can be used on straight polarity d. c. than on a. c.; more on a. c. than on reverse polarity. When in doubt as to electrode diameter, try the smaller size first.

3. Do not break tungsten electrodes—either purposely or accidentally. Nick the rod with a grinding wheel, then snap it off clean with pliers gripped close to the nick. A jagged break (*D*) causes a poor arc. Avoid bending the rod. A bent electrode not centered properly in the collet results in a poor arc and overheating.

The electrode is always brittle $\frac{1}{8}$- to $\frac{3}{8}$-in. back from the welding end. In nipping off a rod to make a clean end (*E*), use the pliers in such a way as to break it as close to the end as possible (*F*). If broken at a point $\frac{1}{2}$ inch or more from the end, you may bend the rod or make a jagged break.

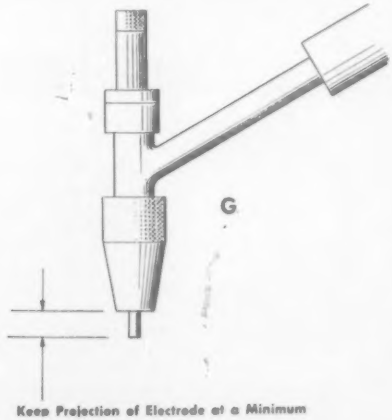




4. Do not start the arc by contact with the work, or with a base metal starting block. This contaminates the end of the tungsten electrode, also contaminates the weld. The arc should be started with high frequency a. c. If this cannot be done, use a tungsten starting block.

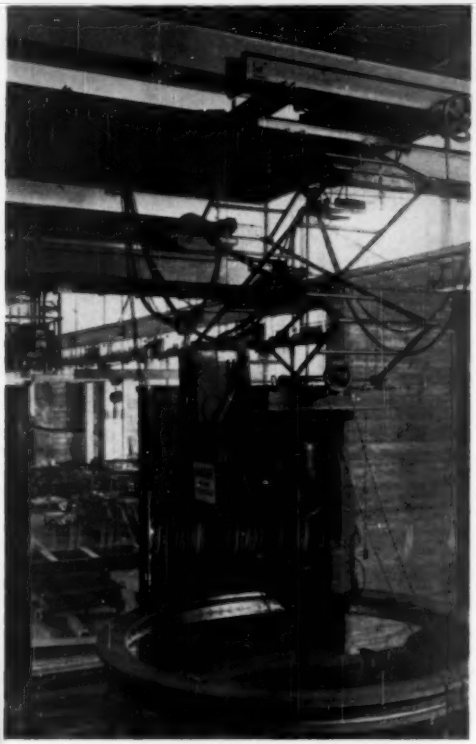
5. After the arc is broken, keep the inert gas flowing to protect the tungsten electrode until it is below red heat. If this is not done, the electrode oxidizes with a blue, black, brown or greenish yellow coating. A properly protected electrode will be bright and shiny, like polished silver.

6. The projection of the tungsten electrode beyond the ceramic gas shield on the torch should be kept at a minimum (*G*). The amount of the projection is de-

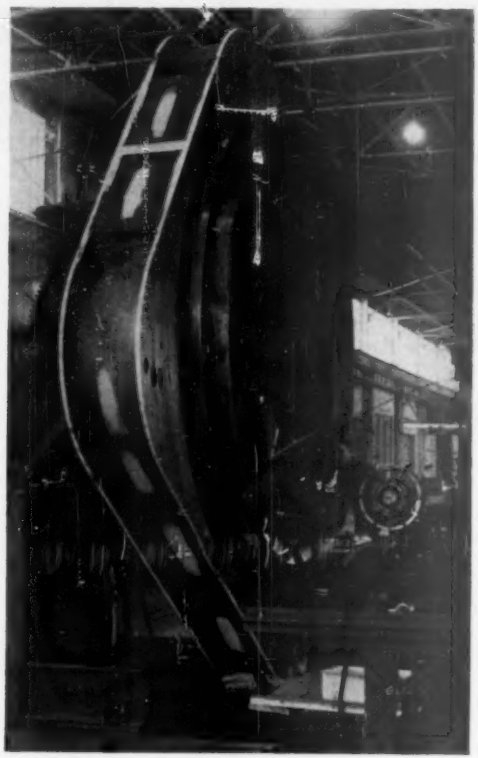


pendent upon the nature of the work, the electrode diameter and the flow of gas. Too long a projection invites oxidation of both the electrode and the weld.

7. Keep the torch, particularly the ceramic gas shield, clean. Spatters of metal from the weld accumulate on the gas shield and the electrode. These in time will cause wandering arcs, poor welds and too much electrode consumption.



Radiographic inspection of welds joining four rolled forging which form a foundation ring. Forty-five radiographs are made simultaneously with a million volt x-ray machine



Photographs, *Courtesy of Northern Ordnance Incorporated Minneapolis 13, Minnesota*

Submerged arc welding used in the assembly of heavy machine base

Some Unused Cover Pictures

A change in cover format has left us with some interesting unused cover pictures, some of which we are reproducing herewith. The balance will be shown in a subsequent issue.

At the top of the facing page is shown a photograph, through the courtesy of the C. F. Braun & Company, illustrating the welding of a head-seam on a vacuum-column head 15 ft.—$7^{1}/_{2}$ in. diameter. Directly below there is a photograph, through the courtesy of the Crane Company—a $17^{7}/_{10}$ in. O.D. × $11^{2}/_{10}$ in. I.D. $3^{1}/_{4}$ in. wall, $2^{1}/_{4}$% chrome, 1% molly hollow bored pipe for a high pressure steam piping system 1970 psi. 1050° F.

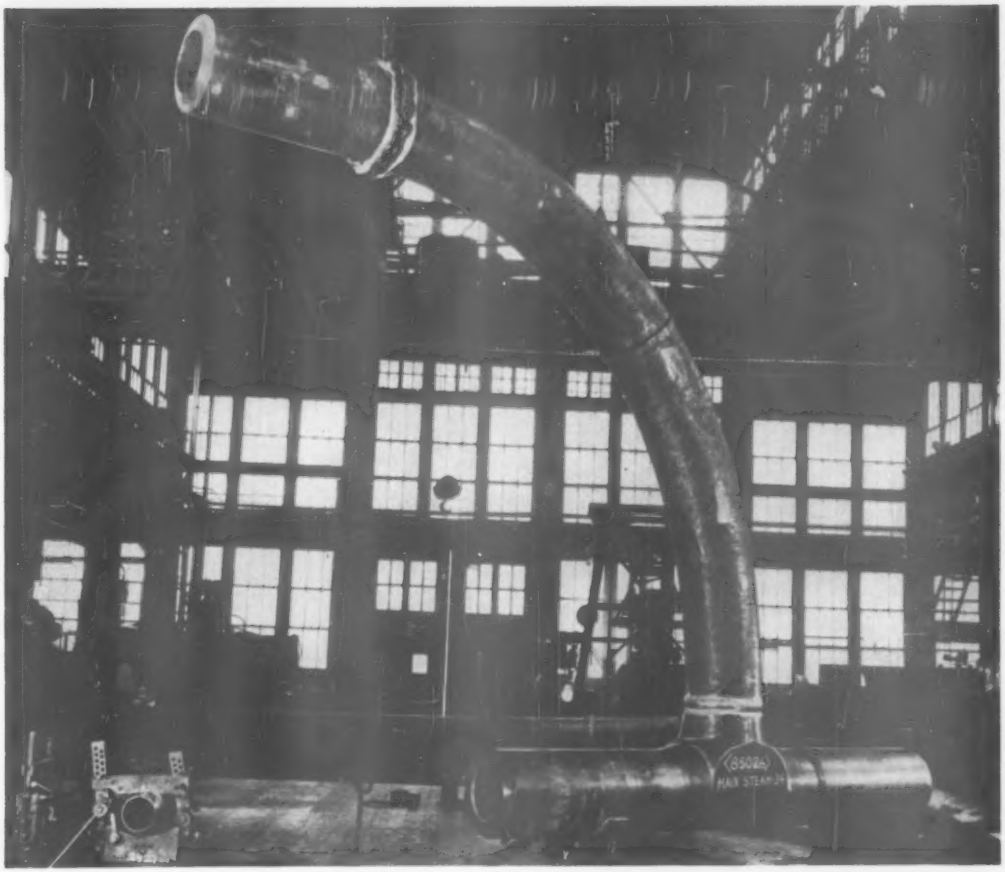

(8502a)
MAIN STEAM

Photo Courtesy C. F. Braun & Co.

Welding-in tubes in converter-tube sheet 126 in. dia. by 240 in. length

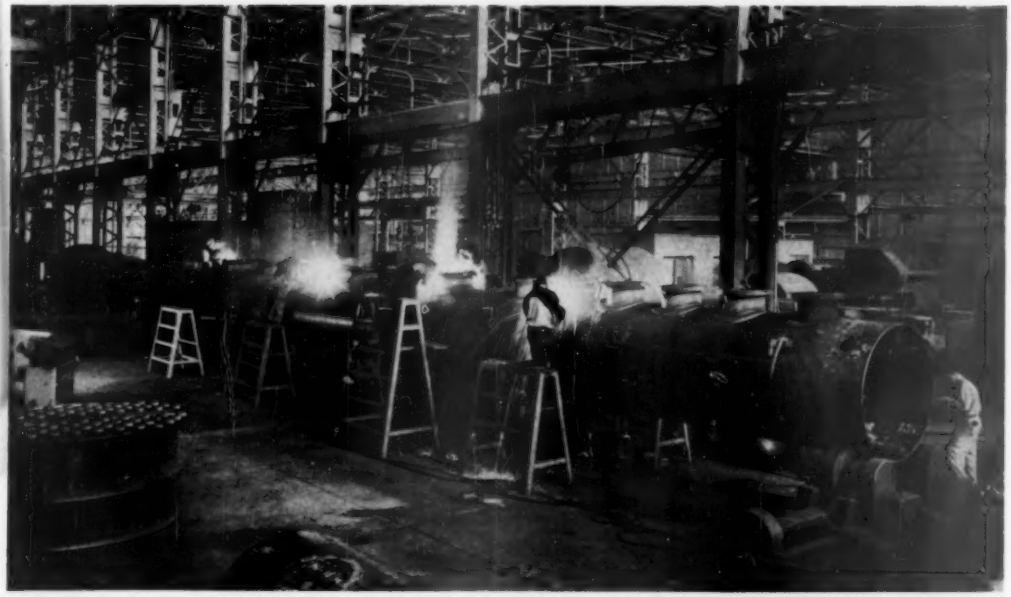
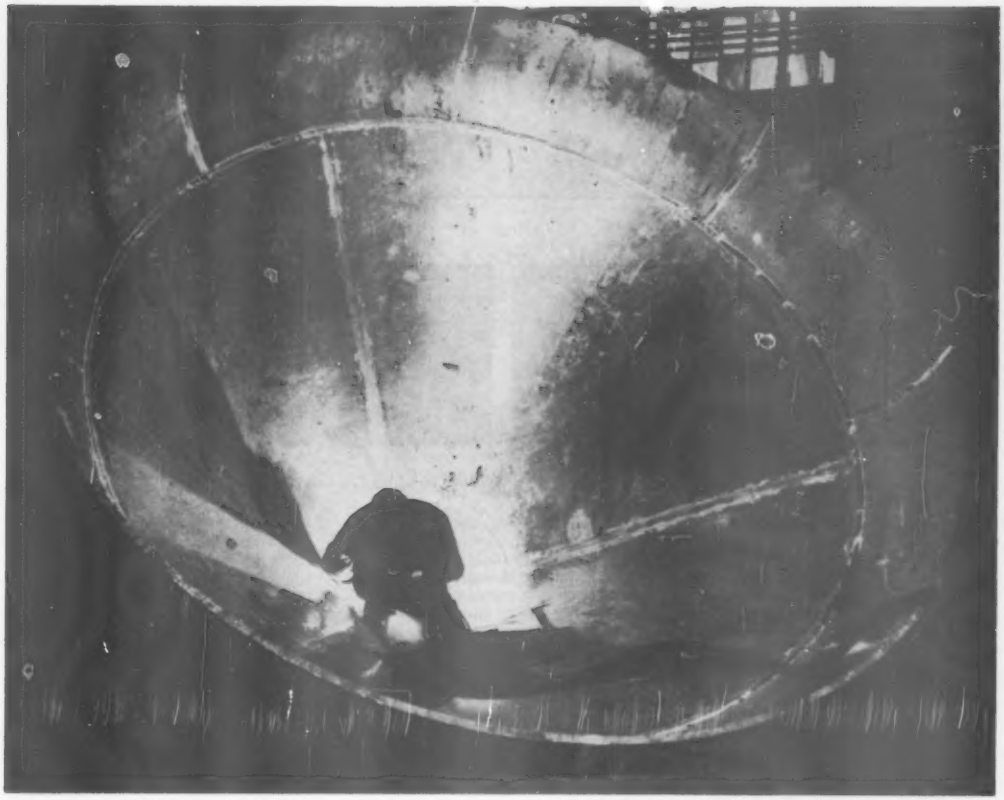


Photo Courtesy C. F. Braun & Co.

Welding manholes on 54 in. diam. absorber-column



Photograph, Courtesy of Foster Wheeler Corp., New York 6, N. Y.

This is a 45° cone bottom for a 12 ft. 10 in. inside diameter tower to operate at above atmospheric pressure and minus 320° F. The plate thickness is $1^{3}/_{16}$ in. and is 3S aluminum, as rolled. The welding was all X-rayed for quality control. The welder is using the manual argon shielded tungsten arc process. This head was one of two fabricated. The work was part of a large contract involving welding of aluminum plates up to and including thicknesses of $2^{1}/_{2}$ in.

Shop Furniture

by L. Gladu

Shop furniture like this will help keep any shop neat. Make the stock bin to a size that will fit your shop. Legs of the stock bin are made from 3 by 3 by $^{1}/_{4}$-in. angle iron. Compartments are $^{3}/_{16}$-in. steel plate.

The tray stand is 18 by 24 in. and has legs made from 1 by 1 by $^{3}/_{16}$-in. angle iron. Strap iron bands, 1 by $^{3}/_{16}$-in. are braze welded between the legs. The tray is cut from 14 ga. sheet—edges are bent up $^{1}/_{2}$ in. to keep tools from rolling off.

L. Gladu, Dominion Oxygen Co., Ltd., Montreal, Canada.

Legs and braces for the tripod are made from 1 by 1 by $^{3}/_{16}$-in. angle iron. These are braze welded to a $1^{1}/_{4}$-in. pipe, 30 in. long. A nut for $^{3}/_{8}$-in. wing screw is braze welded at the top. This makes it easy to raise and lower the center pipe.

the AMERICAN WELDING SOCIETY

activities • related events

Annual Meeting Session on Applied Welding Engineering

Applied Welding Engineering

One of the outstanding features of the 1950 Annual Meeting of the SOCIETY was the session on "Applied Welding Engineering" put on by the Technical Activities Committee of the SOCIETY on Tuesday evening, October 24th. A crowd of about 350 packed the Bal Tabarin of the Hotel Sherman to hear the program which consisted of six talks by nationally recognized welding experts, who are active in the technical work of the SOCIETY, accompanied by a slide film strip. One of the photos herewith is a partial view of the audience.

The program presented, in a concise form, the interrelated factors involved in engineering a welded product or structure. C. D. Evans introduced the session with a general, over-all summary of welding engineering followed by J. J. Chyle who talked on design, A. N. Kugler who talked on material selection, R. W. Clark who talked on workmanship and production quality control and J. Lyell Wilson who talked on inspection. S. A. Greenberg concluded the formal part of the program by discussing a series of different weldments and showing how the same factors were involved in engineering all applications.

Following these talks there was general discussion from the floor, which was only limited by the lateness of the hour. The general concensus of comment about the session was that it was excellent, and that we should have more such sessions at future Annual Meetings.

H. W. Pierce, President-elect of the SOCIETY is shown in a photo concluding the evening's program with a few remarks on the benefit of A.W.S. technical activities to industry.

Panel Discussion on Resistance Welding

An eager and interested audience of about 250 attended the Panel Discussion on Recommended Practices for Resistance Welding on Monday afternoon, October 23rd during the Annual Meeting of the SOCIETY in Chicago.

Sponsored by the A.W.S. Resistance Welding Committee this session was in the form of short talks on welding different metals followed by general discussion from the floor. One of the accompanying photos shows the participants in the program. Reading from left to right (seated) W. J. Wilson, Wilson Scott, E. A. Bussard, R. T. Gillette, J. B. Welch and R. M. Wilson, Jr.: (standing) J. J. MacKinney S. A. Greenberg and Julius Heuschkel.

Because a generous amount of time was allowed for discussion there was a beneficial exchange of ideas and practical experiences by the audience. The A.W.S. Resistance Welding Committee also obtained several valuable suggestions for future activities which would meet the needs of industry.

One of the high lights of the program was the presentation of a watch to R. T. Gillette on his retirement from the General Electric Co. after 49 years of service. The watch was a gift from the A.W.S. Resistance Welding Committee in recognition of Bob Gillette's outstanding contributions to the work of the Committee and to resistance welding in general. The accompanying photo shows Bob receiving the watch from Julius Heuschkel, Chairman of the A.W.S. Resistance Welding Committee.

1950 Bound Volume

Copies of the 1950 Bound Volume of THE WELDING JOURNAL are now available. The price is $15. Order through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Panel Discussion on Resistance Welding

$2250 in Prizes for Papers on Resistance Welding, Design—Application—Research

Announcement has been made of cash prizes to be awarded in 1951 by the Resistance Welder Manufacturers' Assn. for outstanding papers dealing with resistance-welding subjects. The total amount of the awards is $2250, and a wide choice in subject matter is allowed in order to assure eligibility to all papers which cover worth-while and significant achievements in the field. The contest judges will be appointed by the AMERICAN WELDING SOCIETY, and awards will be made at the 1951 Fall meeting of the SOCIETY. The prizes and rules governing the contest are as follows:

One prize of $750 for the best paper emanating from an industrial source, consulting engineer, private or government laboratory, or the like, the subject matter of which is concerned specifically with resistance welding. There are no restrictions on the scope of the subject matter. For example, it may be devoted to redesign of a product or products for resistance welding, improvement (from a welding and cost viewpoint) in a present design for resistance welding, resistance welding research, development of new procedures to broaden the field of application of resistance welding, etc. Papers in these categories should explain the economic importance of the accomplishments described—that is, cost savings, production improvement, scope of application, etc.

A prize of $500 for the second-best paper in the above classification. A prize of $250 for the third-best paper in the above classification.

A prize of $300 for the paper emanating from a University source (the author of which is either an instructor, graduate student or research fellow) which in the opinion of the Board of Award is the greatest original contribution to the advancement and and use of resistance welding from this source.

A prize of $200 for the second-best paper in the above classification.

A prize of $250 for the paper emanating from a University source (the author of which is an under-graduate student) which in the opinion of the Board of Award is the greatest original contribution to the advancement of resistance welding from this source.

While each prize award is the total for the paper, each individual author and co-author, if any, will be presented with a suitable certificate.

The contest is open to anyone, without restriction, from the United States, its possessions and Canada. It is also open to any member of the AMERICAN WELDING SOCIETY in any grade from any place in the world. The contest is considered as having opened Aug. 1, 1950. In order to be eligible for this contest all papers must be forwarded so as to be delivered at AMERICAN WELDING SOCIETY headquarters no later than 5:00 P.M., July 31, 1951. Papers which are to be presented at the Annual Meeting of the AMERICAN WELDING SOCIETY in October may also be entered in this contest, in which case a draft or copy of the paper must be filed with the AMERICAN WELDING SOCIETY not later than July 31, 1951. To be eligible, author must indicate paper has not been considered previously in the contest, or shall not have been presented or published elsewhere prior to its appearance in THE WELDING JOURNAL.

All papers submitted in the contest become the property of the R.W.M.A. and the AMERICAN WELDING SOCIETY, who will retain all rights thereto. The AMERICAN WELDING SOCIETY will appoint five judges, who will judge the relative merits of the various papers submitted and make the awards accordingly. The decision of the judges will be final.

For the author or authors to be eligible for this award, the paper shall describe clearly original work done by them or under their supervision on resistance welding in any of its aspects by any method or process. The paper shall be a full disclosure of the subject. The paper shall contain no statement which is unethical advertising or sales promotion. The paper may contain statements of fact, including the names of either individuals or organizations of any kind, commercial designations, trade names, etc. The minimum length requirement is 2500 words.

All papers must be typewritten, double spacing, written on one side only of blank white paper. Photographs, charts, graphs, etc., may either be attached directly to the copy or may be detached, in which case they should be clearly identified with figure numbers, captions, etc.

Papers entered in this contest should be sent to AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. If mailed to arrive not later than July 1, 1951, three copies should be furnished. If mailed to arrive between July 1, and July 31, 1951, six copies should be furnished.

(*Continued on page 96*)

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PERSONNEL

Dr. H. K. Ihrig Made Vice-President in Charge of Research

Walter Geist, president of the Allis-Chalmers Mfg. Co., Milwaukee, Wis., has announced the election of Dr. H. K. Ihrig as vice-president in charge of research effective since November 15th.

Simultaneous with this announcement, W. C. Buchanan, president of the Globe Steel Tubes Co., Milwaukee, Wis., and a director of Allis-Chalmers, announced that the resignation of Dr. Ihrig as vice-president and director of laboratories of the Globe Steel Tubes Co. was accepted at a meeting of the company's board of directors this week.

Buchanan said, "After 17 years of loyal service, naturally we are reluctant to lose the services of so valuable a man as Dr. Ihrig. However, as a director of Allis-Chalmers and cognizant of that firm's expanding program of research, I know that Dr. Ihrig can make a great contribution. We are extremely pleased that he is going to have this splendid opportunity."

In announcing the appointment, Geist said, "Allis-Chalmers has vastly increased its research program and its research facilities. We have ventured into such divergent fields as medical research and advanced metallurgy, with particular emphasis in recent months on the beneficiation of low-grade ore or taconite for our ever-expanding demands for steel.

"The addition of Dr. Ihrig to our staff will permit us to expand and intensify our work in research."

Dr. Ihrig has already made outstanding contributions in the research field. He was cited in 1949 by the University of Wisconsin college of engineering for his important contributions and inventions, particularly in the field of metallurgy.

In 1947 he was awarded the Robert W. Hunt medal by the American Institute of Mining and Metallurgical Engineers for the best paper published on iron and steel research.

Dr. Ihrig, who holds 19 patents, is a native of Wisconsin. He was born in Appleton, but spent the major part of his youth in Oshkosh. He attented Carleton College and the University of North Dakota. He received his B.S. degree from North Dakota in 1919 and his M.S. degree from that same institution in 1920. He received his Ph.D. degree from the University of California in 1923.

He is a member of the American Chemical Society, American Institute of Chemical Engineers, American Society for Metals, American Institute of Mining & Metalurgical Engineers, American Petroleum Institute, AMERICAN WELDING SOCIETY, The Electrochemical Society and the National Society of Professional Engineers.

He has written many technical papers and has addressed many scientific and technical organizations.

During his 17 years with Globe Steel Tubes Co., he made many outstanding contributions to the steel tubes industry through his research developments.

In the past 2 yr., Dr. Ihrig has served as a consultant for Allis-Chalmers in connection with the company's participation in the work of the Atomic Energy Commission.

OBITUARY

Ralph E. Spaulding

Ralph E. Spaulding, President of the Aetna Steel Construction Co., of Jacksonville, Fla., until his retirement in 1947, died on July 11th at Pasadena, Calif.

Mr. Spaulding was born on Oct. 12, 1884, at Suffield, Conn. He graduated from Worcester Polytechnic Institute in 1909 with degree of B.S. in Civil Engineering. After graduation he instructed at Worcester Polytechnic Institute. In 1917 he was Works Manager of Reinforced Concrete shipyard operated by F. T. Ley and Co., Inc., for the U.S.S.B. Emergency Fleet Corp. in Mobile Ala. From 1920 to 1924 he organized and was General Manager of the Fred T. Ley y Cra Ltda of Lima, Peru. During this period he was in complete charge of design and construction of the first modern buildings ever built in Lima. From 1924 to 1930 Mr. Spaulding was Vice-President of the Fred T. Ley & Co., Miami, Fla. He was in responsible charge of the securing and execution of some fourteen million dollars worth of building and other contracts in the southeastern section. One of his most

important contracts during this period was the Boca Raton Club, a beautiful private club costing 2½ million dollars. In 1928 he organized the Compania Constructora Fred T. Ley, in Santiago, Chile, and, also, in Bogata, Columbia. In 1930 he resigned from the Fred T. Ley & Co., Inc., organizations and in 1931 organized and became President of the North American Construction Co. in Florida. From 1936 to 1947 he was President of the Aetna Steel Construction Co. in charge of all engineering design. Mr. Spaulding retired in 1947. He was a Life Member of the American Society of Civil Engineers, and Member of the American Institute of Steel Construction, AMERICAN WELDING SOCIETY, Structural Steel Research Committee and Fatigue Testing Committee of the Welding Research Council, Registered Professional Engineer of the State of Florida, Georgia and California, Past-President of the Associated Industries of Florida, Inc., Member of the Board of Directors of Jacksonville, Fla., Chamber of Commerce, Past-President and Director, Florida Chapter, American Society of Civil Engineers, Phi Gamma Fraternity and Kiwanis Club of Jacksonville, Fla.

Employment Service Bulletin

Position Vacant

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WELDING
CODES STANDARDS and SPECIFICATIONS

Are you fully informed on the latest welding standards available? Have you missed any of the earlier standards? This column is published as a regularly monthly feature of The Welding Journal to keep you abreast of AWS technical standards, which are universally recognized as the most authoritative source of welding information.

The list of publications shown below is only partial; it is changed from month to month.

Keep informed—Read this column regularly.

B. TRAINING INSPECTION AND CONTROL

Training, Qualification and Inspection

B1.1-45 Inspection Handbook for Manual Metal-Arc Welding (Emergency Standard) $2.00

B2.1-45 Code of Minimum Requirements for Instruction of Welding Operators: Part A—Arc Welding of Steel 75c

B2.2-44T Code of Minimum Requirements for Instruction of Welding Operators: Part B-1—Oxy-Acetylene Welding of Steel Aircraft (Tentative) 75c

B3.0-41T Standard Qualification Procedure (Tentative) 50c

C. PROCESSES

Recommended Practices

C1.1-50 Recommended Practices for Resistance Welding $1.00

C1.2-42T Tentative Standards and Recommended Practices and Procedures for Spot Welding Aluminum Alloys (Emergency Standard) $1.00

C2.1-50T Recommended Practices for Metallizing: Part 1A—Metallizing Shaft or Similar Objects; Part II—Metallizing—Safety Recommendations Together 75c

NOTE: 25% discount to A and B members and 15% discount to C members of AWS on copies of any codes and standards listed above except starred items.

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CORROSION RESISTANCE *Without* COLUMBIUM

If you have had difficulty in obtaining columbium stabilized welding electrodes such as Type 347, you'll find Arcaloy ELC (extra low carbon) electrodes a suitable alternate. Service tests have proven these electrodes equal to stabilized grades and far in excess of ordinary grades.

5 YEARS DEVELOPMENT - 2 YEARS IN SERVICE

As the leading manufacturer of stainless steel welding electrodes, Alloy Rods Company went to work on the problem of eliminating the necessity of Columbium in arc welding as early as December 1945.

Since June 1948, Arcaloy Type 308 ELC (Extra Low Carbon) and Arcaloy Type 316 ELC Electrodes have been used on many weldments in various industries and have proven satisfactory under service conditions.

• Butt weld made with ½" type 304 plate and welded with type 308 electrodes. NOTE dark bands of corrosion due to carbide precipitation in heat affected zones.

• Butt weld made with ½" type 347 plate and welded with type 347 electrodes. NOTE absence of corrosion in heat affected zones, when Columbium stabilized plate and electrodes are used.

• Butt weld made with ½" type 304 ELC plate and welded with 308 ELC electrodes. NOTE absence of corrosion in heat affected zones, when ELC plate and ELC electrodes are used. Compare with type 347 weld (center.)

• Actual size — as welded. Etched 12 hours in 10% nitric — 3% hydrofluoric acid solution at 175° F. Photographs courtesy ARMCO Steel Corp.

CARBON CONTENT IMPORTANT

Arcaloy Types 308 ELC and 316 ELC (Extra Low Carbon) electrodes produce weld deposits containing .03% maximum carbon. In order to achieve complete immunity to inter-granular carbide precipitation in unstablized austenitic alloys, carbon content must be reduced to less than .02%. However, it has been determined that *material containing .03% maximum carbon content will possess sufficient immunity* to safely withstand temperatures in the carbide precipitation range for reasonable periods of time.

ARCALOY 308 ELC and 316 ELC

Arcaloy Type 308 ELC electrodes will weld stainless types 321 (titanium stabilized) and 304 ELC without appreciable carbide precipitation. Arcaloy Type 316 ELC electrodes will weld stainless Type 316 stabilized and 316 ELC plate without appreciable carbide precipitation.

Get all the facts on these new Arcaloy electrodes by writing for a copy of "Arc Welding Stainless Steel Without Columbium."

ALLOY RODS CO.

YORK, PENNSYLVANIA

THE QUALITY LINE IN THE

STEEL CONTAINER

Moisture, dirt and grease proof. Easy to stock.

NEW LITERATURE

Torch Catalog

Air Reduction Sales Co., a division of Air Reduction Co., Inc., has announced the publication of a new catalog on hand torches for gas welding and cutting.

This colorful, 36-page illustrated catalog contains detailed information on Airco's complete line of welding and cutting torches, outfits, tips and accessories. Extensive charts showing correlation of tip, mixer, extension and torch contain complete data for each component part—a torch and tip for every job.

Cutaway views of the various parts of both welding and cutting torches, as well as welding and cutting pressure charts, make this catalog a valuable reference book.

For a free copy of this new catalog (Form ADC-702) write to the Airco sales office nearest you, or Air Reduction, 60 E. 42nd St., New York 17, N. Y.

Metallizing Process Protects Metals Against Heat Oxidation

In a new 4-page bulletin the Metallizing Engineering Co., Inc., describes and illustrates several applications of a process for protecting metals against heat oxidation. Life of these parts has been increased from 200 to 800%.

Write for your copy to Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Data on Chemical Compositions of Seamless Alloy Steel Tubing

The Babcock & Wilcox Tube Co. offers a new technical data card on the chemical compositions of the company's seamless alloy-steel tubing, specifically B & W Croloy steels of the low and intermediate alloy groups. These apply to pipe for high-temperature service and tubing for use in heat exchangers, condensers, refinery stills, boilers and superheaters. Data covers carbon, manganese, phosphorus, sulphur, silicon, chromium and molybdenum content, according to A.S.T.M. specifications. The card, TDC 136, is available on request to The Babcock & Wilcox Tube Co., Beaver Falls, Pa.

In addition to the seamless-steel tubing of the low and intermediate B & W groups mentioned above, the company, with plants at Beaver Falls, Pa., and Alliance, Ohio, manufactures seamless alloy-steel tubing for mechanical applications and seamless and welded carbon and stainless-steel tubing for all pressure and mechanical end uses.

Rebuilding Wheels of Mine Locomotives by Unionmelt Welding

"Rebuilding Wheels of Mine Locomotives by Unionmelt Welding" is a 4-page pamphlet describing the installation at one of the many companies now doing this type of work.

As the wheel is rotated beneath the automatic Unionmelt welding machine, metal is deposited on the tread and up the side of the flange. Usually, the average wheel can be rebuilt in less than 2 hr. The deposition of about 30 lb. of welding rod is required. The deposit is smooth, clean and dense which results in a considerable saving in machining since it is only necessary to take a light cut to produce a smooth surface. Some operators even consider it unnecessary to finish machining the wheels before returning them to service. This folder, F-7346, is available on request from The Linde Air Products Co., 30 E. 42nd St., New York 17, N. Y.

Lightweight Welding Guns

The Progressive Welder Sales Co., 3970 E. Outer Drive, Detroit 34, Mich., has issued a 4-page folder describing their new Magna-Lyte welding guns. Portable welding guns made with Magna-Lyte castings offer added maneuverability, thereby reduce operator fatigue, increase speed of welding operation and improve workmanship. Combined, these benefits result in greater welding production and economy. Copy of this folder is available on request.

Bulletin on Inert-Arc Welding

A new, 8-page, illustrated bulletin covering inert-arc welding—the gas-shielded arc-welding process using helium or argon—has been issued by Metal & Thermit Corp. The bulletin describes the process and its applications, contains a number of operating hints and gives specifications of the required equipment. Copies may be had by writing the company's New York office, 100 E. 42nd St., New York 17, N. Y.

Bulletin on Small P&H A.-C. Welder

A new bulletin, covering the P&H Model TR-180A A.-C. Welder, has just been printed by the Harnischfeger Corp. The bulletin lists all the features of this limited input welder and illustrates a number of its applications.

The Model TR-180A Welder has a Welding Service Range of from 20 to 180 amp. and has the famous P&H "Dialectric" heat control. The capacity of the model makes it valuable for the welding requirements of shops, garages, fabricators, farmers, etc.

A free copy may be obtained by writing the Harnischfeger Corp., Welding Division, 4400 W. National Ave., Milwaukee 14, Wis. As for Bulletin W-71-1.

Vest-Pocket Electrode Guide

Now being distributed is a new 56-page electrode guide, covering all P & H welding electrodes. Of pocket size for easy reference, the electrode guide has page tabs marking the various classifications of electrodes. A helpful feature is the 2-page comparative chart which lists corresponding types of electrodes. The booklet also includes a description of each electrode, typical applications and the sizes which are available.

A copy of the P & H Welding Electrode Guide may be obtained free by writing Harnischfeger Corp., Welding Division, 4400 W. National Ave., Milwaukee 14, Wis. Ask for Bulletin R7-8.

Oxygen Cutting

The wide-scale use of oxygen cutting in the production effort of World War II firmly established this process as the standard industrial method for shaping ferrous metal parts for fabrication. With production of armaments and other equipment again a prime industrial objective, the publication of Slottman and Roper's book, *Oxygen Cutting*, is of particular interest.

Scheduled for release in January by the McGraw-Hill Book Co., this book provides the metal-working industry with a comprehensive and authoritative manual of practical oxygen-cutting techniques, as well as a summary of our present-day knowledge of the subject. In addition to fundamental information on the action of the cutting jet and the mechanism of the process, the book includes extensive discussions of the many uses to which oxygen cutting may be applied, and presents interesting historical background material.

Special chapters are devoted to the effects of oxygen purity, metal temperature, and alloying elements on the cutting action; the effects of oxygen cutting on ferrous alloys; plant facilities; oxygen-cutting equipment; the operation and use of the oxygen lance; hand and machine cutting; electronic tracing devices; multiple and stack cutting; and underwater cutting, to mention several.

George V. Slottman, Director of Research and Engineering, Air Reduction Co., Inc., has been directly associated with the development of oxygen-cutting processes since 1934. He was formerly Professor of Chemical Engineering, Massachusetts Institute of Technology.

Edward H. Roper is Assistant Technical Sales Manager of the Air Reduction Sales Co., a division of the Air Reduction Co. He has a broad background of engineering experience in the field.

Oxygen Cutting is priced at $6.50. For further information contact McGraw-Hill Book Information Service, 327 W. 41st St., New York 18, N. Y.

Increase SPOT WELD OUTPUT

WITH DIVERSEY PRE-WELDING TREATMENT FOR ALUMINUM

The BEST Surface Preparation . . .
Plus the BEST Welding Technique
Produces the BEST Spot Welds!

Photos Courtesy Douglas Aircraft Co., Inc.

Using DIVERSEY No. 36 Cleaner and DIVERSEY No. 514 Deoxidizer

- . . . produces low-uniform surface resistance
- . . . improves quality of welds
- . . . increases quantity of spot welds before tip cleaning
- . . . prolongs life of electrode tips
- . . . eliminates tedious, expensive mechanical cleaning

Yes, if you are looking for higher quality, increased production and lower costs with your aluminum alloy spot welding operation, investigate the Diversey Pre-Welding Treatment today!

Used by leading aircraft companies, case histories reveal that, by employing Diversey No. 36 to remove identification markings, grease, dirt; and by using Diversey No. 514 to remove oxide and heat scale, spot weld output increased up to 50%! Further, plants report an increase up to 1,000% in the number of spot welds now made before the electrode tips require redressing!

The Diversey Pre-Welding Treatment for aluminum is easy, efficient, practical, and surprisingly economical to use! Mail the handy coupon today for complete information!

MAIL THIS COUPON TODAY

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Metal Industries Department
1820 Roscoe St., Chicago 13, Ill.

Gentlemen:
Please send me complete information on the Diversey Pre-Welding Treatment for Aluminum.

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Company_____

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City_____ State_____

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NEWS OF THE INDUSTRY

Netherlands Welding Society

In its Annual Report for 1949–1950 the Netherlands Welding Society announced that it has 4922 members (July 1, 1950) compared with 4194 on July 1, 1948. The Society has 20 local sections and publishes a monthly magazine. The Society's International Contact Committee cooperates closely with the International Institute of Welding. The Research Committee of the Society published several reports on the weldability of steel during the year. Research is progressing on the effect of impurities in steel, on resistance welding, on X-ray studies, on sigma phase, on impact tests and on high-temperature tests. The Research Committee is divided into seven sections: (*a*) weldability, (*b*) alloy steels, (*c*) nonferrous, (*d*) sheet-metal weldability, (*e*) welded structures, (*f*) X-ray studies and (*g*) gas welding.

The Society issued 66 diplomas to students completing welding courses during the year. It offers welding prizes for outstanding papers and conducts several types of instructional courses.

Engineering Undergraduate Award and Scholarship Program

The fourth competition in the Annual Engineering Undergraduate Award and Scholarship Program has been announced by The James F. Lincoln Arc Welding Foundation, Cleveland 1, Ohio. The dates for the competition have been extended this year to include one entire year, June 1, 1950 to May 31, 1951.

All resident engineering undergraduates registered in any college offering a degree in any branch of engineering (including agricultural and architectural) are eligible to participate. Awards totaling $6750 will be made for the best papers on arc-welding design, maintenance, fabrication or research. Awards range from $1000 to $25 for students and duplicate awards in scholarships funds will be made to the schools in which the main award winners are enrolled.

The Foundation states that it is not necessary to know how to weld or to be enrolled in a course studying some phase of welding. The purpose of the program is to stimulate independent study and investigation by engineering undergraduates into the science of arc welding and its possible application in industry and agriculture.

Rules for the program are available in an illustrated booklet giving suggestions for paper subjects, bibliography and showing examples of award winning papers. Write: A. F. Davis, *Secretary*, James F. Lincoln Arc Welding Foundation, Cleveland 1, Ohio.

Purdue Conference Postponed

Purdue University's Welding Conference, Welders' Institute and Exhibit of Welding Equipment and Supplies will be postponed until 1951–52. This action is necessary because of major remodeling of the welding facilities of the Department of General Engineering. Staff members who usually devote a great deal of time to the planning of the conference are confronted immediately with the design of the new plant.

Because of the crowded conditions on the campus housing facilities for the conference will not be available at a time at which the staff is free to participate.

Coming Meetings

Seventh Western Metal Congress and Exposition, March 19–23, 1951, Civic Auditorium and Exposition Hall, Oakland, Calif. This double event is sponsored by American Society for Metals in cooperation with 20 other national technical societies.

Welding Research Competition $1000 in Prizes

Our readers are reminded that R. D. Wasserman, President of Eutectic Welding Corp., announced his company sponsorship of a $1000 Prize Competition for Technical Papers having to do with research and development in the field of "nonfusion" welding processes.

The prize fund has for its purpose the offer of more adequate tangible rewards for scientific and research activity in the branch of welding that has shown important progress in recent years yet remains relatively unexplored.

The Eutectic $1000 prize competition opened Sept. 1, 1950 and closes May 31, 1951. It invites entry of technical papers by persons in both industrial and in educational fields.

Rules governing the competition may be secured by writing to Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Lincoln Changes

John F. Kotchian is now serving industrial accounts for The Lincoln Electric Company as a welding engineer in the Company's Chicago district. He has been transferred from the Cleveland district where he has had, in addition to his regular duties, the special assignment of developing the application of welding for maintenance in service organizations such as bakeries, hotels, office buildings, hospitals, greenhouses, garages and dairies. The use of a welder in the home hobby shop was also another field of special investigation.

Split-Second Fastening

"Split-Second Fastening," the 18-min. color sound movie portraying uses of stud welding in construction, railroad, process and metalworking industries is currently being exhibited to an average of more than 600 persons and 20 groups every month, according to Leonard C. Barr, vice-president and general sales manager of the Nelson Stud Welding Division of Morton Gregory Corp.

Introduced in November 1949, the film has been shown thus far to 256 groups in 117 different cities, and has been witnessed by a total of 8220 persons in a period of 12 months.

Showings may be arranged by writing to the company's headquarters at Lorain, Ohio.

Powder Metal Firm Relocates

Sintercast Corporation of America, an organization specializing in powder metallurgy, has moved its office, laboratory and production facilities from New York City to larger quarters in Yonkers, N. Y.

Until its recent acquisition of the business and equipment of the Wright Carbide Co., East Orange, N. J., Sintercast was primarily a research and development organization.

However, the activities of the firm are now divided into two specialized categories. They are: (1) research into and development of new powder metallurgy techniques and alloys, and (2) production of standard and special-purpose powder metal parts.

Its activities in the production category include the fabrication of: standard and special tools and dies, wear-resistant elements, high-strength parts, heavy duty electrical contacts and welding electrodes, special-behavior contact metals and high-temperature components.

The composition of these parts ranges from the refractory metals and the cemented tungsten and titanium carbides through the sintered irons and steels to the low-melting alloys and includes all types of duplex metal-impregnated material combinations.

PAGE *Welding* ELECTRODES

a NEW line of Page-Allegheny AC-DC Stainless Steel Electrodes

they're NEW

. . . ***BUT*** they've been "given the works" by many large fabricators of stainless steel equipment—on the job. And, from all reports, they're the most all 'round satisfactory electrodes PAGE ever developed for any kind of weld on any type of stainless steel. And PAGE has been making stainless steel electrodes since the early development of stainless.

Ask your Page distributor about these new, improved Stainless Steel Electrodes

ACCO

TRADE MARK

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE

Get in touch with your PAGE Distributor

NEW PRODUCTS

Aluminum Solder Flux

All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y. announced a vastly improved aluminum solder flux that can be reactivated after drying out by the simple addition of tap water.

This new flux can be used with aluminum solder rods of any commercially available brand. It can be used with an open flame and, under certain conditions, with a soldering iron. And, it will make solder flow into the joint, thus enhancing greatly the inherent sealing and pressure-tightness qualities of the solder. It is characterized by such thorough and universal tinning action that it enables soldering aluminum to other metals, e.g., copper, steel, bronze, etc. This flux both cleans the surface to be soldered and deposits a coating of a nature permitting the aluminum solder to flow and adhere.

Alcohol heretofore has been a common solvent for aluminum fluxes. This has been blamed for the short shelf life and waste that have annoyed distributors and users alike.

Since it replaces the previous "flame-permissible" aluminum solder flux in the All-State line, it has been given the same number as the utility aluminum solder—No. 30. It will be known as No. 39 Brazaloy Flux

Thor-Tung Electrodes for D.-C. Straight-Polarity Heliwelding

Thoriated tungsten, long used in electronic tubes because of its excellent electron emission characteristics, is now available as a nonconsumable electrode (Thor-Tung) for Heliwelding—Airco's inert-gas-shielded-arc welding process. This new electrode has proved extremely valuable in d.-c. straight-polarity welding.

Actual tests have shown that Airco Thor-Tung operates much cooler than standard tungsten electrodes, thus permitting the use of higher currents on given size electrodes. Further, Thor-Tung has excellent arc stability not only at these high currents, but also at currents lower than those possible with conventional tungsten electrodes.

Since Thor-Tung runs cooler and does not become molten, consumption is almost negligible and contamination resulting from accidental or deliberate touching is eliminated; touch-starting thus becomes a practical operation, even at low currents.

Because of its permanency, Thor-Tung may be "pointed" to permit continued operation at extremely low currents. This new d.-c. straight-polarity method of Heliwelding aluminum, using Airco Thor-Tung electrodes and helium as a shielding gas, not only eliminates the special problems heretofore encountered in a.-c. Heliwelding, but also provides a hotter, more stable and more efficient arc which produces deeper penetration and faster welding with lower gas consumption per foot of weld and less distortion; special plate edge preparation is simplified or eliminated.

For further information, contact your nearest Airco sales office, or write to Air Reduction, 60 E. 42nd St., New York 17, N. Y.

Lightweight "Heliarc" Torch

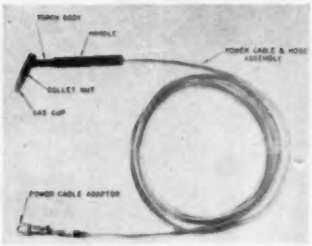
A new, lightweight, air-cooled Heliarc torch for inert-gas-shielded-arc welding is announced by The Linde Air Products Co., a Unit of Union Carbide and Carbon Corp. The torch, which has a two-position welding head and needs no water cooling, has a maximum current capacity for continuous duty of 75 amp. It is designed for welding thin-gage materials.

The new torch, the HW-9, has a torch head and handle assembly weighing only 3 oz. In normal welding operations the torch head is at a 120° downward angle from the handle, as shown in the accompanying illustration. By interchanging the collet nut and torch cap, which is possible with this torch, the angle of the torch head can be changed to a 60° backward angle from the handle. This permits making welds in tight spots, formerly inaccessible.

The collet nut is part of the torch body in the HW-9, and a quarter turn of the nut frees the electrode from the two-piece quick-release type electrode holder. Steel collets are available for 0.020-, 0.040- and $^1/_{16}$-in. diameter electrodes. All three sizes of collets can be used with this collet nut. Two torch caps, made of highly heat-resistant ceramic material, are available for the torch, permitting the use of either the 3- or 7-in. electrodes.

The torch is equipped with a single cable, carrying both power and gas. The cable supplied is 12$^1/_2$ ft. A 24-ft. cable and hose assembly is available as an accessory. The cable has screw-on connections at the torch body and at the adaptor lug, making on-the-job replacement simple.

The entire torch body is sheathed in nylon plastic, safeguarding the operator from electrical shock. The collet nut is insulated with a molded plastic shield, and other parts of the torch are equally well insulated. This protection allows the use of the torch at its maximum rated capacity for long periods of time at great efficiency, and without overheating or damaging equipment.



The lightweight, air-cooled torch can be used with either straight-polarity direct current or high-frequency stabilized alternating current.

The HW-9 Heliarc torch is expected to be used for welding a wide variety of sheet-metal parts, and should also be valuable in the construction and repair of rocket and jet-engine components.

Respirator

A new addition to their fast-growing line of respirators, the No. 2099 Air Line Respirator, is announced by American Optical Co., Southbridge, Mass.

Recommended for such operations as paint spraying, welding, cleaning tank cars, abrasive blasting and similar work, the new air-supplied respirator is especially useful where contaminants are unusually heavy.

The No. 2099 protects against dusts, fumes, vapors, mists, smokes and gases. No filters or cartridges are needed because a continuous flow of fresh air is directed through the hose.

Features include the use of AO's popular R2000 respirator facepiece, a 2$^1/_2$ ft. flexible, nonkinking, rubber-breathing tube plus a 12$^1/_2$ to 50 ft length of $^5/_{16}$-in. diameter air hose. Hose is resistant to oil, grease or gasoline penetration.

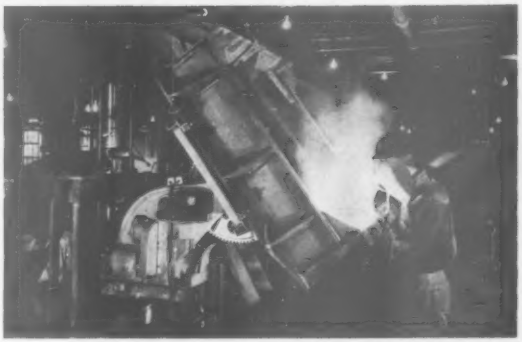
Air flow to the facepiece of the No. 2099 is regulated by an adjustable valve clipped to the worker's belt or clothing. Valve locks in position and cannot be accidentally changed.

You're Smart Like a Fox...

when you increase arc-time per hour with Worthington-Ransome Welding Positioners and Turning Rolls.

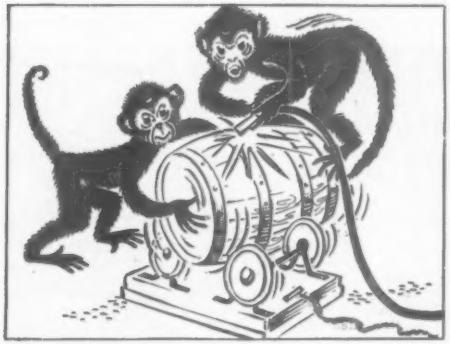
Not this...

Spare your welders the chore of having to *climb* all over the work piece. Climbing, turning, propping time is *waste* time.



But this

With a Worthington-Ransome Welding Positioner continually bringing work into position for convenient down-hand welding, your welders spend less time handling, more time welding.



Not this...

Why do it the hard way when you can get it done the easy way?

But this

Manual or automatic welding really pays off when you use Worthington-Ransome Turning Rolls to rotate the work. This way, output goes up as much as 50% on either repetitive or job work.

Welding Positioner capacities from 100 lb to 20 tons. Turning Rolls from 3 to 150 tons, stationary and self-propelled.

Write for Positioner or Turning Roll Bulletin, Worthington Pump and Machinery Corporation, Welding and Assembly Positioning Equipment Division, Dunellen, N. J.

WORTHINGTON

A detachable hose coupling at the junction of breathing tube and supply hose automatically shuts off air supply when detached. The entire assembly is designed to operate at air-line pressure between 9 and 25 psi.

Modern Manufacturing Plant to Be Built at Union, N. J.

Immediate construction of a new manufacturing plant of approximately 272,000 sq. ft., on a 25-acre plot at Union, N. J., has been announced by John A. Hill, President of Air Reduction Co., Inc.

This new facility, providing for the employment of approximately 800 persons, will be used by the Airco Equipment Mfg. Division of Air Reduction Co., Inc., for the manufacture of welding and cutting torches, tips, regulators, oxyacetylene cutting machines, inert-gas arc-welding machines, acetylene generators, oxygen and acetylene manufacturing and distribution equipment.

The plant, of brick and steel construction and all on one floor except for 18,000 sq. ft. of office space, will be located on property adjacent to the main line of the Lehigh Valley Railroad and within close proximity to U. S. Route 22 and New Jersey State Highway 29.

The general contractor will be David O. Evans of Hillside, N. J., who expects to have the plant ready for occupancy early next spring.

Fig 1. A welding operator using a gun-type Heliarc spot-welding torch

Heliarc Spot Welding Used for United Nations Building

Office doors in the glass, steel and masonry skyscraper capitol of the United Nations were "shot together" with Heliarc spot welding.

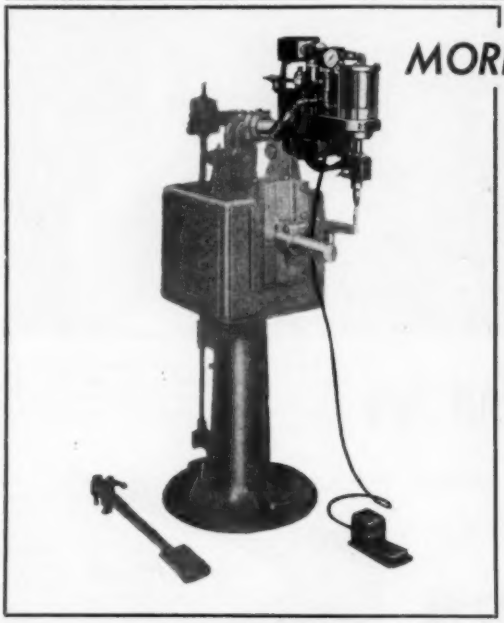
The Atlantic Metals Product Co. of Long Island City, N. Y., fabricators of the doors, said this method cut welding time approximately two-thirds. It also saved time in finishing because the welds were spatter-free and needed little clean-up.

The Heliarc spot-welding torch, a product of The Linde Air Products Co., was used to weld filler strip into the space around the single window in the doors, the flush edges and the hinges. All welds were made from one side, without backing. Each weld took only $2^1/_2$ sec. to make. The welds were made in thin-gage cold-rolled steel.

Arc Welders Tested at 65° Below Zero

Hobart Brothers Co. has started operations of new facilities at Troy, Ohio, to test its products under subzero conditions.

In a special cold room, with an intermediate chamber to reduce cold losses in entering or leaving the cold chamber. Ho-



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Information on Request

MORE SPEED than You Need—
Just Add
WELD-AIR-MATIC
to your Old Rocker Arm Welders

Your present rocker arm spot welders can *really* produce extra profits—for all it takes is the simple installation of a compact Weld-Air-Matic. This self-contained control unit air-powers your welder—adds speed, accuracy, ease of operation never before possible with your present foot-operated welder.

Tests Prove 10,000 Welds Hourly
on Continuous Daily Schedules

The Weld-Air-Matic provides a feather-touch foot switch that controls pressure and energizes a coil on a four-way operating valve. Employing reduced air pressure of 15 to 50 lbs., it has a maximum stroke of 1½" on size 1 unit, 2" on size 2, and 2½" on size 3 unit. Requires any standard Weld Timer and a minimum of 4 cubic feet air supply per minute, with 80 lbs. minimum line pressure. Three sizes available with all accessories mounted to one strong aluminum alloy casting.

Get the facts now on how you can break all previous production records with your present equipment, by modernizing with the new Weld-Air-Matic. You can't lose—for the savings you make will quickly account for Weld-Air-Matic's nominal cost.

WRITE TODAY FOR DETAILS

ROBT. W. HOFFMAN COMPANY, INC.
36 South Clinton Street Chicago 6, Ill.

ELECTRODES

cut welding costs all along the line

OPERATOR

"easy to use"

"I like G-E rods because they are easy to use—I can make more welds per day. And no matter what sort of welding work I have to do, ordinary or special, there's always a 'right' G-E rod for the job."

WELDING ENGINEER

"excellent mechanical properties"

"We can more than meet our specifications by using G-E electrodes. They have excellent mechanical properties—high tensile strength, good ductility, and soundness."

PLANT MANAGER

"for fast and economical production"

"Our plant aims for fast, economical and quality production. At the same time, we want to keep our operators happy with the tools we provide. We chose G-E electrodes because they do both jobs."

PURCHASING AGENT

"high quality product at right price"

"By using G-E electrodes we get a high quality product at the right price—and get it promptly. We can get prompt service right from our local distributor."

Order arc-welders, electrodes, accessories, and renewal parts from your G-E Welding Distributor. For more information, write: Apparatus Dept., General Electric Co., Schenectady, N. Y.

GENERAL ELECTRIC

bart products are now tested at temperatures ranging down to 65° below zero.

Testing equipment consists of a graphic thermometer for continually charting ambient air or room temperature with a range of −100 to +100° F.; an indicating potentiometer which has 24 stations, is self balancing, calibrated directly in ° F. with a range of −100 to +1200° F. with appropriate thermocouples; a two-way sound system so that observers conducting tests can communicate with technicians outside of the room; and an inspection window with 6 panes of thermo-glass to maintain insulation.

Photo shows a technician starting tests on a 30-kw. generator.

Large Weldments

The Ingalls Iron Works Co., of Birmingham and Pittsburgh, an independent structural steel fabricator, has just completed, at its Birmingham Southside plant, several massive weldments for a large new hydraulic press.

This press will be used by the Ingalls Co. to enlarge its existing facilities for structural and plate fabrication and for further production of large weldments of all types.

Frames for this large press, with integral hydraulic cylinders, are of box section with a body width of 20 in. and a width of over-support brackets of 3 ft. 6 in. The over-all height of frames and housings is 19 ft. 8 in. with an over-all width of 14 ft. 4 in. The frame section is 4 in. thick and 20 in. wide with a web plate of 2 in.

Cylinders with a wall thickness of 4 in. and pistons were pressed in semicircular sections and later welded into complete units. The completed cylinders are 5 ft. 8 in. long and were hot pressed to 32 in. outside diameter. The cylinder head is of 6-in. plate. The pistons are also rolled, formed hot to 17 in. outside diameter. They consist of $3^1/_2$-in. plate, 5 ft. 9 in. long. The piston weldments weigh approximately 6000 lb. each, and the completed half section of the press weldment, including cylinder, weighs 29 tons.

Upper and lower platens for the huge press are essentially duplicates, except for slight functional differences. Each platen weighs approximately 25 tons, is 32 ft. in length and 8 ft. high. The platens are of box section with 2-in. web plate and $1^1/_2$-in. stiffener. The heaviest section used is the platen face—8- x 18-in. steel, finished to 7 x 16 in. Other sections are of 6- x 16-in. plate. All weldments were stress before being machined.

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give more protection!

COLONIAL GARMENT KIP SPLITS

- WILL CUT ANY SIZE ONE-PIECE APRON
- FULL CHROME TANNED LEATHER FOR HEAT RESISTANCE
- PEARL COLOR—WEIGHT TO SUIT —WELL TRIMMED

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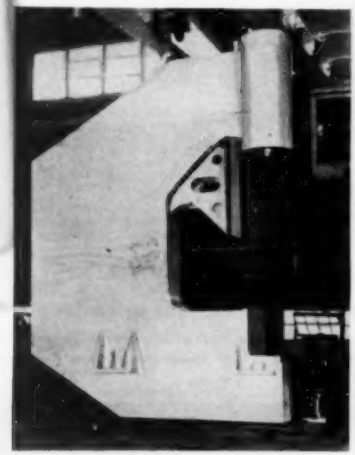

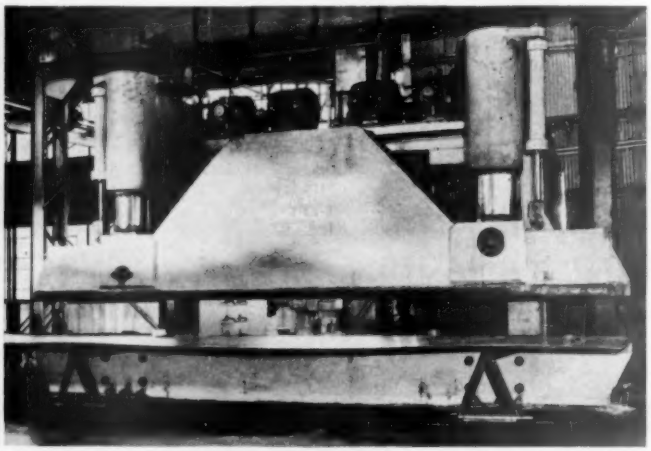

Section of a Giant Hydraulic Press

A superior PRODUCT AT A competitive PRICE!

Wire in special thread-wound coils for submerged arc welding

Grades Regularly in Stock
"RACO" Mild Steel
"RACO" High Tensile
"RACO" High Mang
"RACO" High Mang-Moly
"RACO" Medium Carbon (Surfacing) Wire
Furnished in all standard size thread-wound coils.

YOU profit by these RACO extras: Rigidly inspected high quality steel. Beautiful bright copper coating. All coils uniformly thread-wound and uniform in weight, width, inside and outside diameters to fit your reels. Thread-winding and prebent controlled curvature eliminates unwinding entanglements, waves, kinks. Assures deposition only in welding vee. Assures uninterrupted production.

Wire is drawn, copper coated, and mechanically thread-wound immediately preceding shipment, on machines specially developed by us.

RACO coils are packed and sealed in heavy cartons, and palletized to prevent damage in transit, improper stacking or torn wrappers which result in rust and dirt. Coils are not distorted out of shape by rough handling. Steel-strapped palletized unit-shipments prevent mixing with other consignments at transfer terminals while en route; avoid filing of claims, etc. Fifty-six 25-pound coils, twenty-eight 75-pound coils, eight 150-pound coils per unit pallet at no extra cost to you.

Our special packing and shipping methods reduce your handling, disbursement, and storekeeping costs. Save storage space. Provide easy identification as to type and diameter of wire. Our superior quality and coiling assures superior welds and reduces cost per pound of deposited metal.

The **REID-AVERY COMPANY**
INCORPORATED
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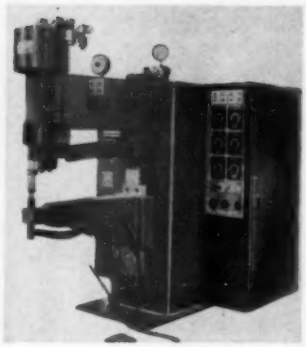
It is the sales policy of The Reid-Avery Company, Inc., to market our products exclusively through distributors and agents. • *Members of* THE AMERICAN WELDING SOCIETY *and* THE NATIONAL WELDING SUPPLY ASSOCIATION

Spot Welder for Aluminum, Ferrous and Nonferrous Alloys

A new resistance welder for spot-welding aluminum, magnesium, stainless steel, Inconel, Monel, brass, mild steel and other alloys has been developed by Sciaky Bros., 4915 W. 67th St., Chicago 38, Ill. This welder is unique in that the same machine can be quickly and easily adjusted to welding, by change of control settings of any one of the above-mentioned metals, and will handle various thicknesses of each. Previously, resistance spot welders have been much more limited in range of material and thickness that any one machine could handle. The new Sciaky PMCO28T "Three-Phase" Modu-Wave welder is designed for welding to Army and Navy specifications and will weld heavier thicknesses of aluminum so that it is applicable to welding various aircraft components including primary structural members. The patented Sciaky Three-Phase System uses up to 75% less current than used by a single-phase welder and operates at approximately 85% power factor as compared to the 30% factor of single-phase machines.

The Sciaky PMCO28T resistance spot welder is a press type machine rated at 100 kva. at 50% duty cycle; operates on 220 and 440 v. three phase, 60 cycle current. Standard throat depth is 36 in.; other depths available. Welding range on low carbon steel is from 0.022 to 0.156 in.



New Spot Welder

(two thicknesses) and on aluminum and magnesium alloys a range from 0.025 to 0.081 in. Ranges for other metals vary.

When welding two or more pieces of substantially different gage thickness uni-directional current is used to insure proper welding. Control of current direction is readily accomplished by operating a simple toggle switch.

For welding of heavy gages of ferrous alloys pulsation controls are provided. The heat and cool time as well as the total number of successive alternating pulses can be controlled. This welder also includes an adjustable pressure regulator for controlling the time at which the forging pressure is applied in relation to the peak of welding current. This assures an optimum weld quality regardless of gage thickness.

Literature describing this welder is available upon request to the manufacturer.

Powder-Scarfing Blowpipe

Stainless-steel slabs can be powder scarfed with greater speed and economy with a new powder-scarfing blowpipe now being marketed by The Linde Air Products Co. Marketed as the Oxweld FSP-2 Powder-Scarfing Blowpipe, it incorporates an arrangement for external powder feed. A wider cut is made than was possible with earlier hand powder-scarfing blowpipes. Width of pass is 2 to $2^1/_4$ in., as contrasted with 1 to $1^3/_8$ in. of pass with older powder-scarfing blowpipes.

Speed of scarfing is doubled with the FSP-2 blowpipe. Due to the increased speed, less powder is used per square foot of scarfed surface, although powder flow rate is the same. For a $1^1/_2$ ton slab, powder consumption has been decreased from 75 to 25 lb.

Another factor bearing on economy of

FOLKS, WATCH THIS DEMONSTRATION IN TWO ACTS AND SEE JUST WHY CHAMPION GRAY DEVIL H.P. IS THE WELDER'S CHOICE WHEN FLAT, SMOOTH WELDS AND HIGH SPEED IS NECESSARY ON THE PRODUCTION LINE. HERE IS AN ELECTRODE THAT HANDLES PERFECTLY IN ANY OPERATOR'S HAND...
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CHAMPION
CHAMPION
GRAY DEVIL H.P.
ONE SECTION EVERY THREE MINUTES... THATS REALLY PUTTING OUT WORK!
RECORD OR NO RECORD I'M PUTTING IN MY BID NOW FOR CHAMPION RODS FOR TOMORROW'S TRICK!
UNLESS THE NIGHT CREW USES CHAMPION GRAY DEVIL H.P. THEY HAVEN'T A CHANCE OF BEATING THIS RECORD!
LISTEN TO THE BOYS... NOW I KNOW WHY CHAMPION GRAY DEVIL H.P. IS CALLED THE WELDER'S CHOICE!
THE CHAMPION RIVET CO.
CLEVELAND, OHIO
East Chicago, Ind.

1940-1950

10 YEARS OF PROGRESS...
and phenomenal user acceptance

Low Temperature **EUTECTIC** WELDING ALLOYS

I should like to thank the welding engineers and the welders of America who have so wholeheartedly supported our efforts. I should also like to renew our pledge of never-ceasing research and continued production expansion in the development of rods, electrodes and fluxes that will bring even greater advances in increased speed, safety, and savings to your welding operations.

Cordially yours,

Richard Wasserman
President

Forty-four years ago, my father began research on a method of joining metals at heats below the melting point of the base metals involved. Later on, I had the privilege of continuing this work with him to the point where we perfected a new metal-joining process utilizing an entirely *different* kind of welding rods and electrodes that *yield radically new results.*

To distinguish our new line of filler metals, we coined the phrase, "Low Temperature WELDING ALLOYS", which is *registered* in the U.S. Patent Office as a *Trade Mark* of this company.

When, in 1940, these vastly improved techniques were introduced to American industry, it was my privilege to establish and to guide a basic policy that was to keynote our activities for the next decade: "CONTINUOUS RESEARCH AND SERVICE".

Today, in our tenth year of uninterrupted progress, the results of that unceasing determination to overcome the failures of old-fashioned, high-heat welding methods may be measured in many ways.

One gauge of effectiveness lies in the long list of EUTECTIC's developments that have become veritable "milestones" in the advancement of American welding techniques:

✓ The first nickel-bearing, copper zinc welding alloy. (U.S. Patents No. 2,279,282 and 2,279,283)

✓ The first nickel-bearing, copper zinc welding alloy containing silver. (U.S. Patent No 2,279,284)

✓ Truly color-matching process for welding cast iron at low heat. (U.S. Patent No. 2,288,869)

✓ Low-melting, high silicon content, aluminum joining alloy for use with specially compounded flux. (U.S. Patent No. 2,481,053)

✓ Low-melting flux specially compounded for use in the welding of ferrous metals. (U.S. Patent No. 2,479,798)

✓ Covering of welding rods with special metallic film. (U.S. Patents No. 2,359,813 and 2,410,850)

✓ Fully machinable, low-amperage electrode for welding cast iron. (U.S. Patent No. 2,410,850)

✓ High-strength electrode for welding aluminum without spatter or fumes. Trademarked: "EutecTrode 2101." (U.S. Patent Pending)

✓ High Quality fluxes used in conjunction with gas rods and electrodes for the welding of aluminum, aluminum alloys and magnesium. Trademarked: "Eutector."

✓ Series of low-melting alloys for color-*matched* joining of aluminum, brass, bronze, copper, and nickel alloys.

✓ AC-DC cutting electrode that cuts, pierces, chamfers *all* metals without oxygen. Trademarked: "CutTrode."

✓ Mass-produced 'contact-type' electrode for swifter, safer welding of steel. Trademarked: "Hand-O-Matic."

✓ 'Easy-to-use' electrode for multiple-pass welding of mild steel without intermediate slag chipping. Trademarked: "Steel-Tectic."

These are only a few out of the full list of over 150 job-proved alloys our company offers today.

Today, as we start our second decade of service to American Industry, EUTECTIC Low Temperature WELDING ALLOYS are specified in over 78,000 plants throughout the nation!

EUTECTIC originated the program of FREE Consultation-Demonstration in your shop. Today, 200 well-trained District Engineers stand ready to serve you from Coast to Coast whenever you say the word.

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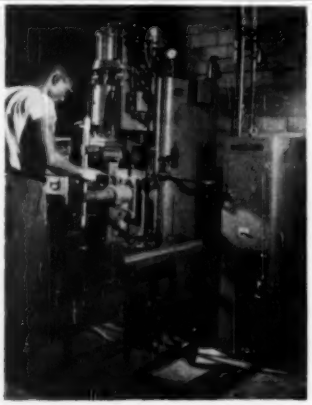
operation of this new powder-scarfing blowpipe is the lessened material loss accompanying the scarfing operation. The product is improved; scale on the surface is cut to a minimum.

In powder scarfing, a finely divided iron powder is blown into the oxygen stream. This powder, heated to ignition temperature by the oxyacetylene preheat flame, burns in the oxygen stream to create the extremely high temperature and slagging action needed to scarf stainless steel.

Better Controls for Resistance Welding

With manufacture of aircraft again greatly on the increase the ability to weld thick aluminum sheets assumes new importance. Resistance welding of aluminum is difficult because its great heat conductivity allows the heat to flow away so fast that poor welds may result. When the war ended in 1945, the thickest aluminum sheet that could be resistance welded and meet rigid specifications of strength, consistency, and freedom from cracks, was not much more than $^1/_8$ in. (0.070). Recently the Thompson Electric Welder Co., using Westinghouse three-phase, low-frequency controls has welded $^1/_8$-in. (0.125)-thick aluminum experimentally.



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Precision Regulation
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The precision performance of the two-stage RegOlator is especially desirable for piped distribution systems and other applications where large volumes of high pressure gases must be controlled accurately.

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Constant delivery pressure regardless of drop in pressure at the inlet...Patented design incorporates nozzle-type first stage counterbalanced by stem-type second stage... Triple action cartridge filter eliminates troubles usually caused by rust, dust or dirt.

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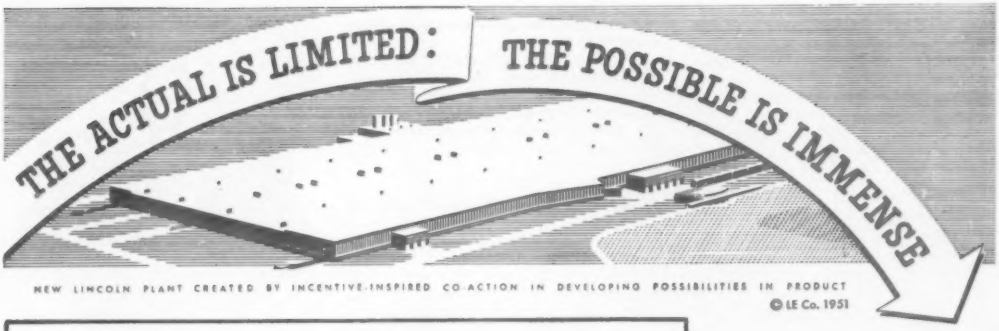
PIONEER AND LEADER IN THE DESIGN AND MANUFACTURE OF PRECISION EQUIPMENT FOR USING AND CONTROLLING HIGH PRESSURE GASES



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

© LE Co. 1951

Manufacturer cuts machining time by converting to welded design

A SAVING of 0.28 man-hours per piece is now being realized in the production of the scale beam shown. By converting the design of this part to welded steel, it has become possible to pre-machine components on smaller equipment as well as eliminate some machining operations entirely.

In place of the original construction shown, the machinery member is now produced simply from a plain angle and two steel straps. The resulting greater strength of the adopted steel design is providing both improved product performance and better sales appeal. The cost of this one part alone has been cut from $2.57 to 71¢ . . . a saving of 72%.

How To Steel Design With Welding. Complete, up-to-date design data now available in new, 9th Edition, Procedure Handbook of Arc Welding Design and Practice. Price only $2.00, postpaid in U.S.A.; $2.50 elsewhere.

Continuous Weighing Machine *of the Schaffer Poidometer Company, Pittsburgh, Pennsylvania. Arrow points to scale beam originally used and now replaced with welded design.*

the **ACTUAL**

Original Construction: *Machinery beam. Cost $2.57 . . . weight 10 pounds.*

increasing the **YIELD**

Present Design: *Simplified with welded steel . . . Costs only 71¢ . . . weighs only 7 pounds.*

the **IMMENSITY** of the **POSSIBLE** turns out to be a **COST REDUCTION OF 72%**

SEE HOW WELDING SIMPLIFIES PRODUCTION

Machine Design Sheets free on request. Designers and engineers write on your letterhead to Dept. 91,

THE LINCOLN ELECTRIC COMPANY

CLEVELAND 1, OHIO

Scaling Hammer

A uniquely designed scaling hammer, forerunner of a complete line of welding tools and accessories, has recently been introduced by the newly organized firm of Jack Churchward Welding Accessories, North Haven, Conn. Other products in this line will be announced shortly.

The patentable features claimed for the Scaling Hammer are: (1) its multipoint hammering surface which speeds descaling by loosening scale not only over a larger surface with each tap, but does it more thoroughly with less effort; (2) its hollow-ground head, which provides the most effective weldscraper yet devised for removing spatter and (3) its slagging pick, which permits accurately pin-pointing removal of slag from weld pockets and corners, is also a scraping tool for removing slag from edges of welds.

Time savings of 30% are also indicated by studies to date. Its well balanced handle reduces worker fatigue. The maker states its principal contribution to the welding industry is better cleaning of surfaces for better welds.

Hydraulic Flash Welder Control

A low-priced control known as "Hydra Flash" has been developed for use with any make of flash welder, new or used, having transformer capacity up to 500 kva. It is a fully hydraulic unit with adjustments calibrated, making duplication of setups as easy as turning a dial. This control, which has been in constant use for approximately one year, enables the flash welder, to which it is applied, to weld any material that is practical to flash weld in any cross-sectional area within the physical and electrical capacities of the welder. The range of cross-sectional areas that any flash welder can accommodate is greatly extended by Hydra-Flash and may be as great as 40 to 1. The simplicity of the control is indicated by the fact that only one limit switch is necessary to operate any standard flash welder. Hydra-Flash will operate several million cycles without maintenance other than regular lubrication. Hydra-Flash has been especially designed for the conversion of mechanically-driven flash welders to hydraulic operation.

For further information concerning Hydra-Flash Control, write Kingsley A. Doutt, 18465 Schaefer Highway, Detroit 35, Mich.

Acetylene Air Torch

A new "Sod-R-Braze" acetylene-air torch featuring a built-in pilot light, a diaphragm type valve and a lightweight plastic handle is announced by the National Cylinder Gas Co. of Chicago. The valve is designed and positioned so that the operator can turn the torch on and off, adjust the flame, and regulate the pilot light all with the thumb of the hand holding the torch. The fire-resistant, plastic

National
Carbide

IN THE RED DRUM

EFFICIENT

ECONOMICAL

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FOR WELDING and CUTTING

Use National Carbide in the Red Drum

Write us for information as to nearest available stock.

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"I read Welding Journal"

Survey after survey shows that Welding Journal is read by approximately 30,000 engineers, executives, designers, draftsmen, supervisors, technicians and practical welders every month . . . reaching the "behind the scenes" purchasing power of the welding industry at the lowest unit cost. Why do these men read the Welding Journal? Because:

1. **Welding Journal** is the official organ of the American Welding Society and the Welding Research Council.

2. **Welding Journal** contains more than 2½ times the editorial material on welding than any other magazine in the world.

3. **Welding Journal** each year gives its readers the results of more than a million dollars' worth of research.

4. **Welding Journal** contains news articles and regular feature sections of direct interest to the practical welder, as well as welding engineers, engineers who are interested in welding, and designers.

5. **Welding Journal's** "News of Industry", "New Products", and "New Literature" sections are the "Bible" of the industry.

SO REMEMBER — WELDING JOURNAL gives you more for your advertising dollar than any other welding publication in the world!

WELDING JOURNAL

handle is grooved to provide cool operation and a firm grip.

Six tips, with individual mixers, ranging from $^3/_{32}$ to $^1/_4$ in. in diameter, permit a wide range of work, from soldering fine parts to sweat fitting and heavy heating. The flame provides sufficient heat to silver-braze copper tubing up to $^3/_4$-in. diameter. A regulator provided with the Sod-R-Braze outfit is adjustable from 0 to 15-lb. pressure, permitting pressure and volume of gas to be adjusted to the requirements of each tip.

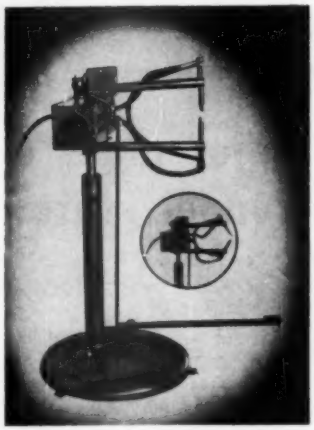
A refrigerant leak detector, which attaches to the torch handle, is available for locating leaks of halogen and other refrigerant gases. It features a reactor unit of high sensitivity.

Announced by N.C.G. at the same time is the "Carryall," a carrying stand built of aluminum tubing which makes the Sod-R-Braze acetylene-air outfit completely portable. It is designed to hold a 40-cu. ft. acetylene cylinder, torch, hose, wrench and torch lighter.

Information on the new Sod-R-Braze apparatus can be obtained from National Cylinder Gas Co., 840 N. Michigan Ave., Chicago 11, Ill.

Pedestal Rocker Arm Welder

A new, interesting and extremely simple spot welder for general use has been announced by Universal Welder Corp., 787 Carnegie Ave., Cleveland 15, Ohio. The Welder is of the rocker arm type—with reversible arms for vertical and slant electrode-holder mounting. The unit pictured here is rated 5 kva., 220 v., 60 cycle, 50% duty cycle in accord with R.W.M.A. practices and can make welds in sheets from 2 No. 28 gage to 2 No. 20 gage steel. Throat depth may be varied from 3 to 15 in. by adjusting the arm length. Arm spacing may be adjusted also and the arms can be swiveled to get into unusual places. Available with both air-cooled and water-cooled point holders. Rugged, foolproof, economical in price and operating cost. Electronic Timers are available if desired.



BECKER

Twenty-eight pages of easily found information, complete with factory model numbers, replacement brush numbers, scaled illustrations of brushes listed, and all other necessary data. Here is a regular "Encyclopedia" of Brush information covering all types and makes of welding equipment.

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SIMPLICITY OF NEW D-C WELDER SLASHES OPERATING COSTS!

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- ★ SMOOTHER WELDING . . . less arc-blow . . . easier arc striking . . . better weld quality.

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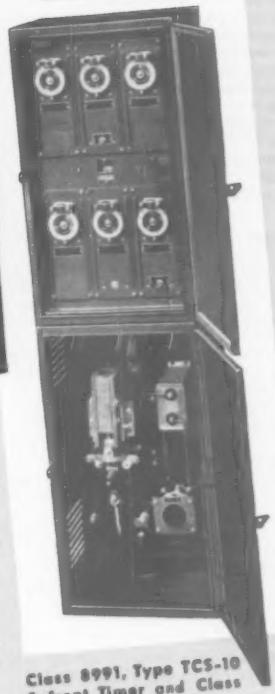
Westinghouse D-C Welders

Specify.. SQUARE D Safront RESISTANCE WELDER CONTROL



FOR CONTINUOUS PRODUCTION—heavy duty rugged construction, hardened moving parts, and accurate, dependable pneumatic timer units.

FOR OPERATOR SAFETY—Safront panel construction isolates individual timer adjustments from live parts. Transformer provides 110 volts for all control circuits.

FOR MOUNTING FLEXIBILITY—Dimensions are standardized. Timers and contactors can be mounted in four different positions for wall or machine mounting.

FOR LOW INSTALLATION COST—Matching knockouts permit close coupling of enclosures, eliminating need for conduit run between contactor and timer.

FOR SIMPLIFIED MAINTENANCE—Accessible mechanical parts and easy coil replacement reduce "down" time and maintenance costs.

When extreme precision or speed is required—use Square D's Electronic Welder Control. Write for Bulletins 8990-8993 which detail the complete Square D line, magnetic and electronic. Address Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin.

Class 8991, Type TCS-10 Safront Timer and Class 8990, Type SCG-2 Syncro-Break Contactor arranged for wall mounting. The same size, neat appearing enclosure is used for 4 and 6 period Safront timers and sizes 1W and 2W Syncro-Break contactors.

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SECTION ACTIVITIES

prepared by C. M. O'Leary

Anthony Wayne

The November dinner meeting of the Anthony Wayne Section was held on the 17th at the Fort Wayne Chamber of Commerce, Fort Wayne, Ind., with an attendance of 30 at dinner. Sporting films were shown for entertainment as a dinner feature and were enjoyed by all.

A good talk on the Design of Weldments and their stress relieving, also, on straightening with a heating torch, such as beams and bent parts from welding and twisted steel sections, was given by J. R. Stitt, Research Engineer, The R. C. Mahon Co., Detroit, Mich. Mr. Stitt's talk was of interest to the engineer, executive and operator. He presented new facts, methods and developments.

Arizona

The November meeting of the Arizona Section was held in the Aluminum Room of the Hotel Westward Ho on Wednesday, November 15th. Approximately 40 members and guests were in attendance.

The meeting was presided over by Arthur Tesmer in the absence of James Johnson, Section Chairman.

Hal Savage, who was one of the two official delegates of the Arizona Section to the Metals Show in Chicago, gave a most interesting report of the Show.

A very interesting and instructive talk was given on "Certification of Welders for State Highway Construction," by Wayne Hunzicker, Chief Inspector, Highway Department, State of Arizona.

A talk on "The Proper Use and Care of Cutting Nozzles" was ably given by Larry Klemmer, Sales Engineer, The Linde Air Products Co.

"Design for Structural Steel Welding," a technicolor film was shown through the courtesy of The Lincoln Electric Co.

Boston

A joint meeting with the American Society of Mechanical Engineers, Boston Section, was held on November 13th at Graduate House, M.I.T., Cambridge, Mass. Dinner was served in the Campus Room with an attendance of 85. Dinner speaker was Mickey Harris, pitcher for the Washington Senators, who gave a talk on "Inside the Club House Doors" which was very well received.

A very excellent outline of the development of the modern welded pressure vessel from riveted and forged vessels was given by M. Christensen of The Babcock & Wilcox Co., before an attendance of 128 members of both Societies.

Chicago

An audience and experts participation meeting was held on September 15th in the People's Gas Light & Coke Co. Auditorium. The entire meeting was devoted to questions and answers with cash awards for answers. This type of meeting is popular in Chicago. The members of the audience ask the questions, and other members of the audience answer them. Judges decide as to the correctness of the answers and the money is awarded in accordance with the answer. There was an attendance of 102 at this meeting. Dinner was held in Burke's Grill and Restaurant.

No meeting was held in October due to the fact that the annual meeting of the Society was held that month in Chicago.

The November meeting was held on the 17th in the People's Gas Light & Coke Co. Auditorium. Dinner was held in Burke's Grill and Restaurant.

Technical speaker was J. H. Humberstone, President, Arcrods Corp., whose subject was "Metal-Arc Welding with Low-Hydrogen Metal Electrodes." Mr. Humberstone presented a difficult subject in an interesting manner. With few slides he held the attention of the audience. An attendance of 110 were present at this meeting.

A film "Wings Around South America" was also shown and enjoyed by all.

Cleveland

R. C. Singleton, Manager of Equipment and Industrial Sales, Nelson Stud Welding Division of Morton Gregory Corp., gave an excellent talk at the November 8th meeting held at the Allerton Hotel.

Mr. Singleton discussed a number of significant applications in construction, steel, railroad, automotive and other production industries. His presentation also described the characteristics of new power sources developed by Nelson for stud welding. Mr. Singleton's talk was followed by a sound motion picture entitled "Split-Second Fastening" in which a large number of stud-welding applications were shown. Mr. Singleton is a very fine speaker; his presentation and subject were good.

Lawrence E. Cooney, Vice-President and General Sales Manager of the Austin Co., gave a very interesting coffee talk—an illustrated travel talk on his Eurasian, African trip. He showed pictures of such scenes as the cave in which the Christ Child was hidden when Herod was killing all male babies, and the Egyptian home of Joseph and Mary. Mr. Cooney's talk was very well received.

Jack Jarms' symposium committee is engaged in applying the finishing touches to the plans for the Cleveland Section's 12th annual Symposium on May 11, 1951.

Colorado

The November 14th meeting of the Colorado Section was held in the Festival Room of the Oxford Hotel, Denver.

Bill Hosokawa of the Denver *Post* gave an interesting account of his experiences on a recent trip to Korea.

Ralph A. Trentham of the Reed Engineering Co., Carthage, Mo., presented an excellent, technical address on "New Tools for Metal Fabrication."

Columbus

The calendar of meetings for the Columbus Section for 1951 are as follows:

January 12th—"Hard-Surfacing," Howard S. Avery, American Brake Shoe.

February 9th—A.S.M. Joint Meeting, "Steel Under Stress," Dr. M. Gensamer, Carnegie-Illinois Steel Co.

March 9th—"Stress Risers as They Affect Welded Design," Paul H. Setzler, Lima-Hamilton Corp.

April 13th—O.S.U. Conference, H. W. Pierce, New York Shipbuilding Co.

May 11th—Annual Meeting, Installation of Officers, Entertainment.

Dallas

The November 15th meeting was held in the Auditorium of the Lone Star Gas Co., Dallas. Dinner was held in Brockles Restaurant.

An illustrated talk giving new facts on High Purity Helium for Shielded-Arc Welding was given by William A. Mays of the U. S. Bureau of Mines. Those in attendance were well pleased with the speaker and his subject.

Refreshments were served after the meeting.

Dayton

On Tuesday, October 10th, the Board of Directors and officers of the Dayton Section had a dinner meeting at Suttmiller's Restaurant. At this meeting, John Blankenbuehler was appointed Assistant Secretary of the Dayton Section. After the dinner meeting of the Board of Directors, the technical meeting was held at the Engineers Club in Dayton.

C. B. Voldrich of Battelle Memorial Institute in Columbus, gave an excellent

talk on the Weldability of Steels. He covered the various characteristics of steels and electrodes as they affected the ease of welding and the serviceability of the weld.

A film was also shown on the Machining and Welding of Magnesium by the Dow Chemical Co.

The meeting was followed by the serving of refreshments.

The Inland Mfg. Division of General Motors Corp. was host to the Dayton Section on Tuesday, November 14th. About sixty members and guests were conducted on a very thorough and tremendously interesting tour of the Inland factories. They saw the manufacture of brake hose, rubber motor mounts, gravel shields, rubber glass retaining strips of all kinds, refrigerator gaskets, plastic parts for automobiles and refrigerators, ice cube trays, brake lining and clutches. The trip through the plant took over 3 hr. and refreshments were served during the trip.

Detroit

The regular monthly meeting of the Detroit Section was held on November 10th at the Engineering Society of Detroit.

The dinner was attended by 49 men who heard an excellent talk on "Alcoholism is an Illness," and it was unfortunate that more members were not present to hear this talk since the information which the speaker provided should be in everyone's possession. The speaker, who is a Chemical Engineer, covered the subject using himself as a subject and, since he spoke from his own personal experiences, did a very convincing job in his presentation.

Ted Jefferson, Editor of *The Welding Engineer*, did his usual good job on "Welding and Its Roll in the Present and Future of America." The basis of his paper was to convince those present of the selling job we in the welding industry, and particularly in the AMERICAN WELDING SOCIETY, have to do on industry in order for welding to achieve its proper place as a highly regarded processing tool. While this talk was completely nontechnical, Mr. Jefferson cited many actual examples to prove his various points. While in the case of the Detroit Section, Mr. Jefferson addressed our own membership, the Section feels that his talk would be excellent for a combined meeting of the AMERICAN WELDING SOCIETY and some other technical society where the importance of welding sales efforts might bear some fruit.

Hartford

The Hartford Section held its regular monthly meeting on Thursday, November 9th at the Rockledge Country Club, West Hartford, Conn.

Captain Charles F. Griham (Ret. U.S.N.) spoke informally on his varied experiences in the Navy. This meeting was very interesting to everyone. Captain Griham knows how to hold interest with subject, humor and human interest experience.

Houston

The November 16th meeting was held at the Ben Milam Hotel, Houston, with an attendance of 83 at dinner and 85 at the technical meeting.

A. E. Wisler, District Vice-President, presided as Chairman in the absence of L. F. Megow. H. F. Crick introduced new members and guests, and also reported the Houston Section now has over 150 members.

Technical speaker was J. E. Dato of The Linde Air Products Co. Mr. Dato discussed the relatively new argon metal-arc method of electric welding. Through the use of slides, Mr. Dato illustrated his talk, pointing out various applications of fabrication with particular emphasis in the manufacture and repair of chemical and oil-field equipment.

Indiana

The Indiana Section believes that members benefit greatly from physical demonstrations and that best interest is developed in the SOCIETY activities when these are periodically provided.

At its November meeting, held on the 17th, demonstrations and uses of meters and slopes in welder servicing, as well as the use of capacitors for improving power factor, were started at 1 P.M., and continued up until the time of the meeting. There were made available Gun, Pedestal and Bench type Welders for demonstration with various Meters and Oscilloscopes for anyone to use, if they so desired.

A dinner was held at 6 P.M. at the Phillipe Graham Co., Inc. plant in Indianapolis; 135 interested people attended. An evening meeting followed starting at 8 P.M. and lasting until midnight.

Stuart Rockafellow of Robotron Corp., Detroit, gave the audience an insight into the workings of fully Electronic Welding Timers, from a specially designed demonstration board.

A. G. Petrasek of R.C.A., Camden, N. J., demonstrated the proper use of Meters and Oscilloscopes.

J. W. Kehoe of Westinghouse Electric Corp., Pittsburgh Plant, gave a talk on Welding Standardization. This paper won him the 1950 first prize for the best R.W.M.A. Industrial Paper.

Mr. Bostwick of Cincinnati, Ohio, talked on Power Factor.

All of these talks were of interest to all levels of the audience, who finally went home not from lack of interest but because they could not hold open their eyes.

Kansas City

The regular monthly meeting of the Kansas City Section for November was held on the 16th at Fred Harvey's, Union Station, with an attendance of 29 at dinner and 44 at the technical session.

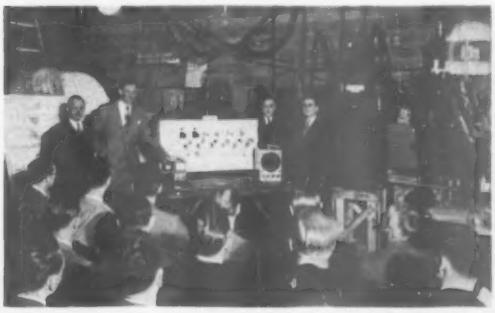
Ralph A. Trentham of the Reed Engineering Co., Carthage, Mo. was the technical speaker. His subject was "New Tools for Metal Fabrication." Mr. Trentham has the background and knowledge for interesting discussions on welding and machines for metal forming.

Lehigh Valley

The monthly meeting of the Lehigh Valley Section was held December 4th at the Hotel Bethlehem, Bethlehem, Pa. "Educational Needs of a Welding Engineer" was the topic of a Coffee Talk given by Dr. Gilbert E. Doan of Lehigh University.

A panel discussion followed the dinner. J. R. Fairhurst, Section Chairman, acting as Moderator, introduced the following members of the panel. Each panel member gave a short discussion on the following subjects: "Oxyacetylene Cutting Equipment," Wayne D. Price, Air Reduction; "Mild Steel Electrodes," A. T. Bavaris, Lincoln Electric Co.; "Shop Fabrication," Vance Edwardes, Ingersoll-Rand Co. and "Welding Metallurgy," Leon McGeady, Lafayette College.

The discussion period covered all phases of welding. It proved to be a very interesting discussion with many of the members and guests taking part in a question and answer period.



November 17, 1950 Meeting, Indiana Section

Los Angeles

The Los Angeles Section made a plant visit to the Kaiser Steel Mill in Fontana for the regular November meeting. Approximately 150 members and guests enjoyed a most interesting and educational tour through all phases of this West Coast Steel mill.

Maryland

The first indoor meeting of the Maryland Section was held on October 20 at the Engineers Club of Baltimore.

Prior to this meeting on September 16, a plant visitation through the Riverside Plant of the Consolidated Gas Electric Light and Power Co. of Baltimore actually started off this year's activity. The above company first provided a luncheon, followed by a short talk by R. C. Fitzgerald. The group of 43 was then divided into smaller groups, and personally escorted through the plant by guides. This plant is the newest one of the utility company and has a present capacity of 180,000 kw.

The after-dinner speaker at the October 20th meeting was E. R. Swint of the Glenn L. Martin Co., who spoke briefly on "Human Relations and Technical Management." Mr. Swint mentioned that in a large organization, such as Martin's, it is not too difficult to get men together to solve a difficult engineering problem; but that the same group would fall down badly when encountered with a human relation problem. The concluding portions of Mr. Swint's address concerned a talk that he had heard three years ago by a famous psychologist who concluded his speech by referring to a chapter of a book which contained the secret to all human relation problems. This chapter, which contains 2700 words and can be read in 15 min., is found in St. Matthew, Chapters 5 to 8, and is entitled "The Sermon on the Mount."

The main speaker of the evening was Arthur J. Raymo, Manufacturing Engineer of the Baldwin Locomotive Works. The subject of Mr. Raymo's speech was "Fabrication of Locomotives by Welding." Mr. Raymo has witnessed the rapid acceleration of the growth of the Diesel locomotive and the gradual decline of the demand for the steam locomotive. Mr. Raymo's talk was augmented by slides, one of which showed the new steam-turbine locomotive which operates as a noncondensing unit at 200-lb. pressure and 700 to 900° temperature.

The boiler which was formerly riveted and subject to leaks resulting in costly upkeep is now a welded and leak-free member. Diesel locomotives are an all-welded structure, except for the truck; and they are working to overcome this last obstacle.

Slides were shown and commented upon. One of the slides showed a welded truck which was fabricated for the cost of the casting pattern. Many welded trucks are in service, but the users have been reluctant to accept 100%.

Michiana

Believing that learning comes not only from hearing, but also from seeing, the Michiana Section continued its 1950–51 season with a demonstration in arc welding by Robert Bercaw, "head master" of the Hobart Welding School. Since much of the emphasis in recent demonstrations has been on the newer or more unusual processes, this one was designed to present basic arc-welding techniques, as a sort of refresher course.

Some 40 members and guests gathered in the Oliver Corp. plant to watch Mr. Bercaw put his welder through its paces. A lively discussion following the demonstration was evidence of the interest of those assembled.

Photo taken at recent meeting New Jersey Section. Left to right—O. B. J. Fraser, past president of A.W.S., Walter Begerow, Chairman of New Jersey Section, and G. O. Hoglund, Aluminum Company of America, speaker

Milwaukee

The November dinner meeting of this Section was held on the 17th at the Ambassador Hotel.

The technical speaker was W. L. Kennicott, of Kennametal, Inc.

Mr. Kennicott discussed the proper methods of attaching tips to steel blanks and subsequent grinding of them. He explained the various points by means of diagrams on the blackboard.

An interesting coffee talk after dinner was presented by Harry Dietterich, a local district commander of the Boy Scouts of America. He gave some interesting highlights of his experience with the 40,000 Boy Scouts from all over the world gathered at Valley Forge last summer.

New Jersey

The November meeting of the New Jersey Section was held in the Terrace Room of the Essex House Hotel, Newark, N. J., on November 21st. A 6:30 dinner preceded the meeting with 49 members and guests attending.

The regular meeting started with the showing of a film furnished by the Third Naval District entitled "Naval Photography in Science." Walter Begerow, Chairman, then turned the meeting over to W. Benz, Acting Chairman of the Program Committee, who in turn introduced the speaker of the evening, Lew Gilbert, Editor, *Industry and Welding*. The subject chosen by Mr. Gilbert was "Welding in the Job Shop." Mr. Gilbert's background as an inspector, welding operator, chief test welder, welding engineer and technical sales engineer, proved him to be a qualified speaker on this subject and offered many excellent suggestions and possibilities for operators of small and large job shops. Members and guests participated in a discussion following Mr. Gilbert's presentation, the consensus of opinion being that his talk was very interesting and well received by all present. A total of 76 members and guests were present. Refreshments were served following this session.

New York

The New York Section held its second meeting of the season on November 14th when Charles H. Jennings, Manager, Arc-Welding Engineering Dept., Westinghouse Electric Corp., Buffalo, N. Y., spoke on the subject, "Proper Preparation for Welding." Mr. Jennings is well known to A.W.S. members as the First Vice-President of the Society.

Mr. Jennings presented an interesting and informative talk dealing with the proper planning and preparation necessary to produce a satisfactory welded job. In his talk he called attention to the fine work the American Welding Society and the various committees functioning under its jurisdiction have done in preparing codes, standards, qualification tests and procedures and specifications for the welding industry. Mr. Jennings pointed out that economical and high-quality welding start in the drafting department and depends upon proper coordination through the engineering department and shop. In his paper he mentioned that in some cases it would be advisable to consider redesign of a part in order to use all the advantages of a specific welding process. He called attention to the great strides which have been made in the welding industry in the past several years.

J. Mikulak, Research Engineer, American Car and Foundry Co., New York, an Associate Member of the Executive Committee of the New York Section, served as

technical chairman introducing Mr. Jennings and conducting the discussion period which followed presentation of Mr. Jennings' paper. The paper was very well received as was evidenced from the interesting discussion which followed.

Prior to the technical session, a demonstration of air-borne radar was presented through the courtesy of the New York Telephone Co. Mr. Britnell of the Telephone Co. described the work that was done in radar and sonar during the last war. A film entitled "Echoes in War and Peace" was also shown.

The Section was honored in having F. E. Garriott, a member of the Executive Committee of the Milwaukee Section, present at the meeting; as well as Professor M. Okada of the Department of Engineering, Osaka University, Osaka, Japan. Professor Okada is an authority on strain testing of metals and is prominent in the Japanese Welding Society. He is presently in this country studying American welding methods under Government auspices. J. G. Magrath, Secretary of the AMERICAN WELDING SOCIETY, introduced Professor Okada and in his behalf read an address of acknowledgment to the New York Section.

In accordance with the Section custom, the meeting was preceded by dinner held at Schwartz's Restaurant, 54 Broad St., New York. Meeting arrangements were made at A. W. Zuethen and A. M. Setapen, Program Chairman.

The following is the Education Program on "Arc Welding Design and Application" sponsored by the Education Committee of the New York Section.

1. Wed., Feb. 14th, Welding Processes, Jay Bland, New York Naval Shipyard.
2. Wed., Feb. 21st, Materials of Construction, Thomas Armstrong, International Nickel Co.
3. Wed., Feb. 28th, Introduction to Design: (*a*) Types of Joints; (*b*) Strengths of Joints; (*c*) Stresses in Joints A. N. Kugler, Air Reduction Co.
4. Wed., Mar. 14th, Design of Welded Structural Steel, La Motte Grover, Air Reduction Co.
5. Wed., Mar. 7th, Design of Welded Pressure Vessels, H. C. Boardman, Chicago Bridge & Iron Co.
6. Wed., Mar. 21st, Design of Welded Piping, F. S. G. Williams, Taylor Forge & Pipe Works.
7. Wed., Mar. 28th, Cost Estimating and Economy in Design of Welded Structures, Omer Blodgett, The Lincoln Electric Co.
8. Wed., Apr. 4th, Code Requirements for Welded Structures, Lyell Wilson, Consulting Engr.

Meetings will be held on the 13th floor of the Consolidated Edison Auditorium, 4 Irving Place (14th St.), New York City. The fee is $7.50 for Members and $10 for Nonmembers. Lecture and Discussion from 7 to 9 P.M.

Niagara Frontier

The following are the meetings of the Niagara Frontier Section for the coming year.

Jan. 25, 1951—"Stump the Experts," Teams from Rochester, Erie, Toronto and Buffalo Sections will compete.

Feb. 22, 1951—Raymond Freeman, Manager of Welding Engineering, General Electric Co., will speak on "New Arc-Welding Equipment Developments."

March 22, 1951—Will be announced.

April 26, 1951—Mr. Arthur N. Kugler of Air Reduction Sales Co., will speak on "Brazing and Bronze Welding."

May 26, 1951—Will be announced.

All meetings will be held at the Sheraton Hotel, 715 Delaware Ave., Buffalo, with dinner at 6:30 P.M., and meeting at 8 P.M.

Northwestern Pennsylvania

The regular monthly meeting for September was held at the Shrine Club, Erie, Pa., on the 19th with an attendance of 45 at dinner and 57 at the technical session.

R. K. Allen, Section Technical Advisory Committee Chairman, familiarized the members with the Section's newly acquired library and the duties of the Technical Advisory Committee.

E. J. Cox, of Pittsburgh Commercial Heat Treating Co., presented a clear cut, interesting talk on Flame Hardening.

An excellent plant visit to the Bucyrus Erie Co., planned by A. Brosig, was attended by 35 of the members and guests.

The October meeting was held on the 18th at the Central Electric Community Center, Erie, Pa., with an attendance of 29 at dinner and 32 at the meeting.

J. M. Diebold of the Precision Welder and Machine Co., presented a highly interesting talk on Resistance Welding.

R. K. Allen, Chairman, Technical Advisory Committee, presided at a question and answer period, in which all took part.

Refreshments and social period followed the meeting.

The November 21st meeting was held at Souden's Restaurant, Erie, Pa., with an attendance of 36 at dinner and 43 at the meeting.

A plant visit to the General Electric Co. was enjoyed by the 34 who attended.

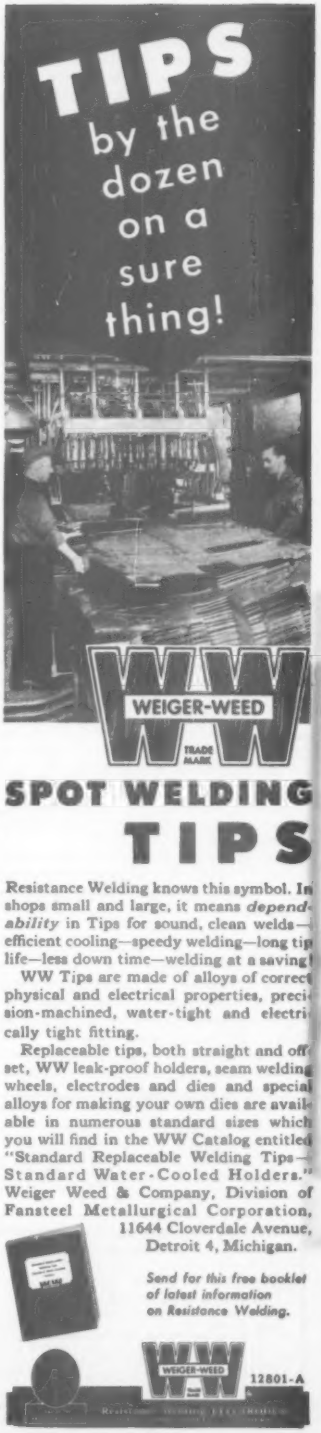
Speaker at the technical session was Ernest DiLiberti of the Air Reduction Sales Co., whose subject "Inert-Arc Welding" covered new facts and methods.

Oklahoma City

The second meeting of the season of the Oklahoma City Section was held on Tuesday, October 10th at the Biltmore Hotel.

R. A. Trentham, Production Manager, The Reed Engineering Co., Carthage, Mo., gave an interesting illustrated talk on "New Tools for Metal Fabrication." Mr. Trentham covered some of the more recent developments in jigs and fixtures for fabrication, with emphasis on those used in connection with automatic welding.

The third meeting of the season was held on Tuesday, November 14th at Jack Barnes Club Room. Speaker was William A. Mays, Metallurgical Engineer, United States Department of the Interior, Bureau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of Mines, Helium Division, Amarillo, Tex. Mr. Mays discussed the effects of different impurities on the welding of aluminum and described the recent revision of helium production processes used by the Bureau of Mines for providing the welding industry with helium of suitable purity. Some of the recent applications for high-purity helium in welding, metallurgy and scientific fields were outlined.

Tentative schedule of meetings for the Oklahoma City Section for the remainder of the season is as follows: January—Stainless Steel Welding; February—Hardsurfacing; March—Live Welding Demonstration; April—Electrodes; May—Low-Temperature Welding and June—Annual Stag Party.

Pascagoula

The Pascagoula Section held its regular monthly dinner meeting at the Pascagoula Country Club, November 8th, with 32 in attendance.

The meeting was under the Chairmanship of J. F. Bryant, Chairman of the Section. The Technical Speaker was Alec Mair.

Mr. Mair is a Graduate of the Royal Technical College, Glasgow, Scotland, where he graduated as a Naval Architect. He started his Shipyard career with the William Denny & Co., Shipbuilders, in Scotland. He came to the United States in 1930, where he joined the Engineering Staff of Federal Shipbuilding Corp. He later served with the United Shipyards at Staten Island and with the Naval Architects' Firm of George G. Sharp. Now, in the Engineering Staff of The Ingalls Shipbuilding Corp., Mr. Mair, is a member of the Society of Naval Architects and Marine Engineers and the AMERICAN WELDING SOCIETY. He is at present, Vice-Chairman of the Pascagoula Section of the A.W.S.

Mr. Mair spoke on "Ship Structural Failures," which was followed by a round table discussion, which lasted some 45 minutes.

Peoria

The November 15th dinner meeting was held at the Jefferson Hotel, Peoria, Ill., with an attendance of 40 at dinner and 45 at the technical session.

Technical speaker was Cecil C. Peck, whose subject "Tooling for Automatic Arc Welding" was of interest to the executive, as well as, the engineer and operator.

Philadelphia

The November meeting of the Philadelphia Section held on the 20th was most successful in bringing us up-to-date welding information as well as a pleasant evening with other men interested in welding.

George Richardson of the General Electric Co., after first showing a film on the principles of the jet engines and its applications, spoke on "Welding Aviation Gas Turbine Components." The importance of welding in these engines was emphasized in the film as well as in Mr. Richardson's talk. The close tolerances and quality of welds that are required have led to careful consideration of the welding process to be used for each part of the engine. As a result numerous processes are used. The questions and discussion, with Frank Gardiner of the I.T.E. Circuit Breaker Co. as discussion leader, made everyone realize the importance of choosing the right welding process to suit the conditions of each part of the weldment.

The coffee talk following the dinner provided an answer to many of our questions on traffic and parking conditions in Philadelphia. Robert Mitchell, City Traffic Engineer, covered the subject of "Off-Street Parking" in a thorough manner. He emphasized the tremendous amount of work to be done to provide a satisfactory solution to the parking problem in Philadelphia.

The Panel Discussion Meeting on Dec. 1, 1950, covered "Resistance Welding as Applied to Production in Small and Large Shops." The subject was presented by the panel with E. S. Ellwood, Taylor Winfield Corp., covering "Control and New Control Features;" K. W. Ostrom, K. W. Ostrom & Co., covering "Design for Welding;" H. F. Merchant, The Progressive Welder Co., covering "Portable Equipment" and C. W. Middlestead, C. W. Middlestead Co., covering "Proper Selection of Electrodes and Electrode Material" as well as acting as moderator for the general discussion. A thorough and clear picture of the use of Resistance Welding was drawn by the panel presentation and general discussion that followed.

The number of guests that have been at both our regular meetings and panel discussion meetings represent potential new members to the Philadelphia Section. Membership in the AMERICAN WELDING SOCIETY and attendance at our meetings can help them obtain the latest information on welding and have a part in the general interchange of welding ideas that is beneficial to everyone.

A membership campaign to enroll new members has been set up under the direction of C. W. Middlestead, Membership Chairman. Three competing teams have been formed to carry on the active Campaign.

Red: K. W. Ostrom, Team Captain: 1. C. Dooley, 2. W. Twiford, 3. M. J. Bonowitz, 4. C. Schaub, 5. E. S. Ellwood, 6. C. H. Davis, Jr., 7. J. Dunne, 8. A. B. Gordon, 9. J. W. Thistle and 10. R. A. Guenzel.

White: A. M. Garcia, Team Captain: 1. C. O. Cooper, 2. J. N. Childs, 3. R. B. Clements, 4. R. D. Bradway, 5. A. J. Erlacher, 6. C. T. O'Callahan, 7. H. F. Merchant, 8. F. W. Cunningham, 9. F. J. Gardiner and 10. W. W. Whitley.

Blue: L. D. T. Berg, Team Captain: 1. J. S. Douglas, 2. C. H. Benker, 3. R. D. Thomas, 4. R. S. McCracken, 5. M. W. Brewster, 6. F. D. Gramm, 7. R. S. Phair, 8. J. C. Cunningham, 9. D. H. Buerkel and 10. H. M. Pfeffer.

Lets all get behind this campaign to make our Philadelphia Section stronger through a larger, more active membership. Help your favorite team to win.

"High - Temperature, High - Pressure Steam Piping," the subject at our joint meeting with the Society of Naval Architects and Marine Engineers on Jan. 15, 1951, is a live topic that insures an interesting evening for all who attend.

The February meeting, to be featured as National Officers Night, will present a question and answer competition to be set up in the form of a spelling bee. The questions will be selected to draw out and present useful, up-to-date welding information. The contestants will be experts from the various fields of welding.

The Panel Discussion meeting on Feb. 2, 1950 will cover "Allowances for and Control of Shrinkage Due to Welding." This will be followed by the closely related subject of "Prevention and Control of Cracking Due to Welding" at the March 2, 1951 panel discussion.

Pittsburgh

The regular monthly dinner meeting of the Pittsburgh Section for November was

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held on the 15th in Hotel Webster Hall, with an attendance of 41 at dinner. The technical session was held at Mellon Institute, with an attendance of 105. This was a better than average attendance both at the dinner and meeting.

Chairman Morgan made an announcement of future meetings, as well as, the coming Tri-State meeting.

Technical speaker was John H. Berryman, Asst. Mgr., Air Reduction Sales Co., New York. Mr. Berryman gave a very capable discussion of Aircomatic Welding of Copper-Base Alloys. A film "The Right Tool for the Job" was very well received.

Portland

The second meeting of the fall season was attended by twenty-two members and guests who met in a private dining room of the Washington Hotel, on October 10th.

After a dinner hour, the meeting was called to order by Chas. J. Daniels, Chairman, at approximately 8 P.M.

The minutes of the preceding meeting were read and approved.

A short business session followed: Paul Kullberg, Industrial Specialties Co., discussed minutes of a past Directors' Meeting regarding technicalities of procedures governing regular meeting sessions. The point in question involved predinner activities. A motion was made and seconded to have a short social session preceding the dinner hour. A vote was taken with 15 voting for and 2 against such activities—the motion carried. However, it was decided that such rules governing meeting procedure should be taken up at the next directors' meeting. Further action was deferred until that time.

E. H. Weil asked for assistance in planning future programs and in contacting members to increase attendance at meetings.

T. Williams was commended for his fine work on securing new members. He gave a report on his activities and asked each member to strive to get another member for the next meeting. Mr. Smith was asked to assist on the membership committee.

A short report on the technical committee activities was made by Chas. Daniels in the absence of James Gow.

The principal speaker of the evening was introduced by C. H. Weil.

The speaker, Collin Chisholm, Manager Steel Division, Woodbury and Co., gave an interesting talk on "Steel" and its position in the present war economy.

The meeting was concluded with the showing of a sound movie film entitled "An Oregon Vacation" shown through the courtesy of the Associated Oil Co. and the Hyster Co.

The meeting was adjourned at 9:30 P.M.

Rochester

The regular monthly dinner meeting of the Rochester Section was held on November 20th at the Century Sweet Shop. The dinner which preceded the meeting was attended by thirty-six members and guests.

Vice-Chairman Harry Stoler, acted as master of ceremonies for a quiz program, "Stump the Experts." Nelson Carter, Joe O'Rourke, Francis Spotts, Paul Ecklund and Nelson Martin were the experts. A very interesting and enlightening evening was enjoyed.

The Section reports that one of its members, Ted Milatz of Eastman Kodak Co., has secured 10 new members so far this year.

St. Louis

Regular technical meeting for November was held on the 10th at the Forest Park Hotel. Speaker was J. R. Wirt of the Delco Remy Div. of G.M.C. Mr. Wirt's subject, "Development of Production Welding Techniques" was well presented with slides depicting special jigs and fixtures designed for special welding applications on automotive parts. Some of the members in attendance were astounded with the high production achieved by Mr. Wirt in his plant and showed considerable interest in some of his special welding techniques.

The Annual Christmas Party was held on December 1st at the Forest Park Hotel. Cocktails were served before dinner, commencing at 6:30 P.M. Dinner was served at 7:30, with an impromptu welcome being extended to the 61 members and guests by the Vice-Chairman, Pete Salsich, who presided.

Following dinner, those in attendance joined in group singing accompanied by an accordionist. Those not in good voice contented themselves with poker, dominoes, elbow exercises and good fellowship.

The party continued to the wee hours of the morning, and many favorable comments were extended on the success of the function.

Susquehanna Valley

Dinner speaker at the November 8th dinner meeting held at the Hotel Sterling, Wilkes-Barre, Pa., was A. G. Leake, a pioneer in the welding field, who spoke of his welding experience. Mr. Leake's talk was interesting and well received.

Technical speaker was Dr. H. C. Campbell, Assoc. Research Director, Arcos Corp., who presented a good, clear-cut talk on "Metallurgy for the Welder." A film "History of Tool Steel Forming of Aluminum" was also shown and viewed with interest. Fifty members and guests attended the meeting, while 37 were present at dinner.

A business meeting preceded the technical session, at which 12 members were present.

Washington

The Washington Section held their monthly meeting on November 28th at the Engineers Club of Washington, Inc. Informal dinner was served at 6:45 P.M. The technical session started at 8:00 P.M. Mr. Fritz Albrecht of The Glenn L. Martin Co., showed a colored film on aircraft and gave a very interesting talk and discussion on aluminum welding in various processes which was enjoyed by the entire group. The Section was pleased to have present two guests from the Spanish Embassy, Lt. Col. Edwardo Prado and Major Carlos Iniesta.

Western Massachusetts

Before the largest audience in recent years, Jim Craig and Lou Bowser of The Linde Air Products Co., gave a combined talk and demonstration on "Inert-Arc Welding." Preceding the technical portion of the meeting, a dinner was held on November 14th at Blake's Restaurant in Springfield, which was attended by 22 persons.

Following the dinner, the meeting adjourned and reconvened at Braun's Welding Service in West Springfield, which is operated by Kurt Braunschweig, a member of the Western Massachusetts Section, for a talk by Jim Craig on the basic theory, equipment and technique of inert-arc welding. This was supplemented by a practical demonstration by Lou Bowser on inert-arc welding. Approximately 60 members and guests were present for the technical session.

Wichita

Twenty-six members were present at dinner held at The O. A. Sutton Corp. on November 13th, while 42 members and guests attended the meeting, which was addressed by Ralph A. Trentham of the Reed Engineering Co., Carthage, Mo. Mr. Trentham's subject was "New Tools for Metal Fabrication."

Mr. Don Schwartz, Sales Manager of The O. A. Sutton Corp., gave a talk on "The Vornado Fan." An inspection tour of the O. A. Sutton Corp. Plant including the small motors division, tooling department, paint shop, sheet metal shop and final assembly, took place after the meeting.

Worcester

Eighty-five members and guests attended the dinner meeting held at the Tower House on November 29th.

Following the dinner at 7:00 P.M. George Wilson, of Air Reduction Sales Co., introduced the guest speaker, Ernest DiLiberte, Welding Specialist for the Air Reduction Sales Co. of New York.

Mr. DiLiberte's talk featured the new Aircomatic process of automatically welding aluminum, stainless steel, bronze, copper, and other alloys. He also showed an "Airco" technicolor movie "The Tool for the Job." This film showed the fundamental research and development of the Aircomatic process. His slides showed various applications where the Aircomatic Process might be used. Welding overhead, vertical and horizontal was particularly interesting to many.

Documentary films taken during World War II showing actual fighting scenes aboard our aircraft carriers preceded the dinner.

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,526,624—METAL REMOVING DEVICE—Albert H. Adams, Lima, Ohio, assignor, by direct and mesne assignments, to Kwik-Arc, Inc., Cleveland, Ohio, a corporation of Ohio.

Adams' patent relates to a device wherein a frame is provided for positioning an electrode, and which also positions an oxygen supply nozzle. The nozzle is adjustably positioned with relation to the electrode and a control valve is provided for control of flow of oxygen through such nozzle.

2,526,723—CONTINUOUS LONGITUDINAL SEAM WELDER—Laurence J. Berkeley, Danville, Ill.

This patented apparatus is for forming longitudinal seams in tubular articles, and includes a series of pressure rolls. The axes of rotation of these pressure rolls are in planes substantially at right angles to the longitudinal axis of the tubular articles to be welded. The axes of rotation of some of the pressure rolls are selectively adjustable to avoid spiralling of the tubular articles as they are being welded.

2,527,235—FLUID COOLED WELDING APPARATUS—Roger W. Tuthill and Alanson U. Welch, Jr., Holyoke, Mass., assignors to General Electric Co., a corporation of New York.

This electrode holder is adapted for use in gas blanketed electric arc welding and it is provided with a special resilient electrically insulating gasket which helps to define a fluid circulating path in the apparatus for passage of a coolant material therethrough. A special electrical and gas supply means is also provided in the apparatus.

2,527,336—CONTROL OF PLURAL ARC WELDING—Walter S. Schaefer to Republic Steel Corp., Cleveland, Ohio, to a corporation of New Jersey.

This patent relates to a method of interrupting operation of a plurality of arc-welding means wherein a series of arc electrode rods are arranged along the weld path and individually fed toward the work while energized to produce arcs. Relative movement is produced between the work and the electrode rods and the energization of a leading electrode rod is interrupted at a desired end of the weld path, whereas a subsequent one of the electrode rods is continuously energized until moved to the locality of the work which was occupied by the leading electrode rod when its energization was interrupted, so that metal continues to be deposited from said subsequent rod whose arc is extinguished while the rod is in the vicinity of the locality at which the leading electrode rod was de-energized.

2,528,040—METHOD OF BRAZING AND WELDING—Logan R. Crouch, Jackson, Miss.

This patent relates to a special bonding method for securing a nipple to a pipe wherein the pipe is provided with a continuous circular raised boss and a stepped seat provided along the inner and upper surface of the raised boss. The end of the nipple to be bonded to the pipe is provided with an enlarged base flange adapted to set within the seat and to conform to the seat provided by the raised boss, and the flange is joined within the seat to the pipe by a brazing composition.

2,528,810—INDUCTION HEATING AND WELDING—Harold L. Zimmerman, Milwaukee, and Frederick J. Van Zeeland, West Allis, Wis., assignors to Chain Belt Co., Milwaukee, Wis., a corporation of Wisconsin.

The patented heating method is suited for use with a longitudinal section of metal positioned in a stationary tubular article and a single conductor is arranged inside and outside the article to induce current in opposite directions throughout the length of the article. This conductor is disposed closely adjacent the surfaces of the section to be heated and a concentrated heating action is produced upon the portion of the conductor passing through the article by conducting the current back through the article by way of a single conductor disposed closely adjacent this last-mentioned portion of the first conductor in a direction opposite to that passing through another portion of the conductor so that the magnetic field created by such currents within the article itself may oppose each other and induce eddy currents and concentrate them in such section of the tubular article.

2,528,835—WELD TIMER—Jacob Kurtz, Teaneck, N. J., and James D. Waldie, New York, N. Y., assignors, by mesne assignments, to Sylvania Electric Products, Inc., a corporation of Massachusetts.

This patented weld timer includes a work circuit, means including a gaseous discharge tube and a first relay controlled thereby for determining the total time from a starting time during which current may flow in said work circuit. Additional means including a second discharge tube and a second relay are also provided in the apparatus, which second relay has a contact in the work circuit in series with the contact for the first-mentioned relay for determining the time intervals of current flow in such work circuit during the total operative time circuit controlled by the first-mentioned relay.

2,529,111—CONTROL FOR WELDING MACHINES—Arthur W. Steinberger, Elizabeth, N. J., assignor to Curtiss-Wright Corp., a corporation of Delaware.

Steinberger's welding current regulating system comprising means for varying a supply of welding current and means responsive to such current according to the magnitude thereof. Further means are provided and are operable according to a welding current schedule, while further means are jointly controlled by the welding current responsive means and the scheduled means to selectively produce alternate sense control quantities with respect to a reference value. Yet further means are controlled by such last-mentioned means according to the sense of welding current.

2,529,265—DEVICE FOR INDEXING CONTACT SPRINGS IN CONTACT-WELDING APPARATUS—Morris Rose, Chicago, and Jerry John Zak, Lombar, Ill., assignors to Kellogg Switchboard and Supply Co., Chicago, Ill., a corporation of Illinois.

This patent covers a specialized device of the character indicated in the title of the patent and it positions the contact-receiving portion of spring blanks selectively in a plurality of predetermined positions relative to the contact-welding means of the machine.

2,529,715—ARC WELDING METHOD AND APPARATUS—Joseph M. Tyrner, New York, N. Y., and Nelson E. Anderson, Scotch Plains, N. J., assignors to Air Reduction Co., Inc., a corporation of New York.

In this patent, the method disclosed eliminates the harmful effects in an a.c. arc-welding system transformer which would otherwise be caused by the flux produced in the transformer core by the magnetomotive force created by any d.-c. component of current flowing through the secondary winding of the transformer as a result of partial rectification in the arc. An auxiliary alternating current is induced in the transformer, rectified and then utilized to produce an additional magnetomotive force which opposes the magneto-

motive force produced by any d.-c. component of the welding current.

2,529,812—Method of and Apparatus for Arc Welding—Vladimir Peters, Lakewood, Ohio, assignor to The Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

Peter's welding method relates to forming a seam between two juxtaposed metallic workpiece edges, and it consists in simultaneously traversing the line of juncture between such edges with two electric arcs, one from each side of the seam to be formed and substantially oppositely positioned to each other. Metal is provided to form the seam simultaneously from opposite sides thereof, while the arcs provided are capable of fusing the seam to more than half the depth thereof so that a common pool of molten metal is formed by the conjoint action of the two arcs.

LIST OF NEW MEMBERS

November 1 to November 30, 1950

ARIZONA

Mc Eowen, Albert V. (B)

BIRMINGHAM

Alexander, John C. (B)
Atchison, F. W., Jr. (C)
Mc Gimsey, Ben Q. (C)
Wilcox, D. V. (C)

BOSTON

Alexander, Edward E. (C)
Canavan, Harold M. (C)
Johnston, James H. (B)

CHICAGO

Adler, Melvin S. (B)
Baetzel, Edmund R. (C)
Johnson, Ruel (B)
Lizer, Kenneth C. (B)
Pape, John J. (C)
Stuart, Duane (C)
Young, Otis H. (C)

CLEVELAND

Fulton, Russell F. (C)
Hannum, Richard M. (B)
Snow, Charles H. (B)
Stevens, Wayland H. (C)
Williams, Frederick Donald (C)

COLORADO

Berens, Karl (C)
Lindemann, Henry (B)

COLUMBUS

Bruce, Arthur P. (B)
Dowman, Richard B. (D)
Helmbrecht, Herbert L. (D)
Rhoads, Loy D. (B)
Roth, Robert Edwin (D)
Young, William, Jr. (D)

DALLAS

Bays, C. W. (C)
Hughes, Lloyd W. (C)
Rose, Rolland H. (D)
Whitman, Robert E. (D)
Zerbe, Paul (D)

DAYTON

Berchtold, Bernard (C)
Bernhardt, John V. (D)
Favorite, Charles W. (C)
Jones, Gerald N. (D)
Kran, Henry (D)
Thomas, Jesse N. (D)
Young, Maurice Eugene (D)

DETROIT

Bourque, Philip (B)
Carpenter, John P. (C)
Catt, Melvon G. (B)
Dell, Lloyd C. (B)
Graham, Steuart P. (B) (October New Member)
Kredo, Theodore J. (B)
Moniak, Eugene (B) (October New Member)
Neubauer, Otto (B)
Powers, William S. (C)
Smith, Gerard S. (D)
Wood, Edward L. (B)

HARTFORD

Coury, Nicholas P. (C)

HOUSTON

Alexander, June L. (B)
Avis, M. C. (C)
Bain, George Victor (B)
Beeson, S. M. (B)
Blackstock, C. E. (B)
Bryan, Samuel, Jr. (C)
Cox, Leonard A. (C)
Kane, John J. (B)
Kegg, Thomas J., Jr. (C)
Liner, W. R. (C)
Mc Cormick, K. A. (C)
Mc Vey, P. W. (B)
Nelson, John C. (C)
Perry, W. L. (C)
Reilly, John J. (C)
Reuter, Joseph E. (C)
Rigsby, H. P. (B)
Sherman, O. R. (C)
Ward, J. A. (C)

INDIANA

Barker, Harold E. (B)
Culbertson, Russel P. (B)
Johnson, Alvin B. (B)

KANSAS CITY

Hollandsworth, J. L. (B)
Mauck, Orville, (B)

LEHIGH VALLEY

Deshler, Walter B. (C)
Gehringer, Arthur M. (C)

LOS ANGELES

Bishop, Sheridan (C)
Graux, Jack L. (C)
Green, E. F. (C)
Mikesell, A. L. (C)

MARYLAND

Kroft, Albert M. K. (B)
Mc Cormack, B. A. (C)

MICHIANA

Beaton, James (C)

MILWAUKEE

Gaulke, Thomas R. (B)

NEW JERSEY

Bilinsky, John (B)

NEW YORK

Danaher, Joseph M. (C)
Egan, Pierce A. (C)
Tour, Sam (B)
Wagner, Lee O. (B)

NIAGARA FRONTIER

Sellers, James M. (C)

NORTHERN NEW YORK

Shultis, William P. (C)

NORTHWEST

Bowman, Paul W. (B)
Docken, Gilbert M. (C)
Heer, Ralph W. (B)

NORTHWESTERN PA.

Anderson, Walter A., Jr. (C)
Miller, Ray (B)
Robertson, Donald C. (C)

OKLAHOMA CITY

Blakley, Thomas E. (D)
Fultz, John A. (D)

PASCAGOULA

Balingit, J. M. (C)
Bates, Thomas M. (C)
Fletcher, Hugh (C)

PEORIA

Caldwell, D. L. (B)
Riegel, G. C. (C)
Shafer, Harvey B. (C)

PHILADELPHIA

Jones, William P. (C)
Landrum, R. J. (B)
Mosbach, William (C)
Stone, Robert A., Jr. (B)
Verbeck, John T. (B)

PITTSBURGH

Conroy, George J. (C)
Valente, Daniel R. (C)

RICHMOND

Wise, William P. (B)

ROCHESTER

Cleggett, Horace V. (C)
Currie, John W. (C)
Federation, Micheal (C)
Foley, John (C)
Hatch, Arthur (C)
Jones, Albert (C)
Mc Innes, Harold A. B. (C)
Prescott, Leonard (C)
Reber, Bernard F. (C)
Shepler, Wilfred (C)
Vonhof, William (C)

SAGINAW VALLEY

Koca, Harlan J. (D)
Michell, R. G., Jr. (D)
Moran, Benjamin E. (D)
Wolcott, John W. III (D)
Wood, Walter F. III (D)

ST. LOUIS

Fisher, George A., Jr. (B)
Kupferer, Earl R. (B)

SYRACUSE

Callahan, William (C)
Church-Smith, William A. (C)
Hawthorne, Lowell H. (B)
Novak, John J. (C)
Waterbury, Warren V. (B)

TRI-STATE

Keener, Charles E. (C)

TULSA

Jensen, A. C. (B)

WASHINGTON

Wetmore, Daniel M. (B)
Williams, Morgan L. (C)

WESTERN MASSACHUSETTS

Amberzon, Russell J. (B)
Keiderling, W. Conrad (C)
Sullivan, Vincent T. (C)

WESTERN MICHIGAN

Adams, George K. (C)

Harvey, Douglas J. (C)
La Due, Douglas E. (B)
Seyfried, Ray M. (C)

WICHITA

Faessler, W. Vincent (B)
Fouse, Warren L. (D)

WORCESTER

Caranchini, U. S. N. (C)
Duffney, David N. (C)
Garland, Albert F. (C)

YORK-CENTRAL PA.

Carpenter, Arthur R. (B)
Marsh, Gerald E. (B)

NOT IN SECTIONS

Chester, John B. (B)
Dean, Albert (C)
Effat, Ahmad M. (B)
Mac Donald, Leslie S. (B)
Marks, John (C)
Marshall, Alexander (B)
Matsuyama, Yutaka (B)
Okada, Minoru (B)
Olin, Xavier Francois (B)

Members Reclassified

DETROIT

Houck, Harry D. (C to B)

NEW YORK

Schuster, William H. (C to B)

NORTHERN NEW YORK

Gillette, R. T. (C to E)

WORCESTER

Sloan, John F. (C to B)

NOT IN SECTIONS

Kneiper, James E. (C to B)

(*Continued from page 85*)

Society Seeks Assistant to Technical Secretary

The AMERICAN WELDING SOCIETY is expanding its technical activities to meet the increasing demands made upon it by industry for authoritative information on welding. To assist in this program the SOCIETY is seeking an engineer to join Headquarters' Technical Staff as Assistant to the Technical Secretary.

Following is a general description of the duties of this position together with a list of general qualifications for candidates.

A. General Statement of Duties

Under supervision, to make notes, prepare and construct minutes of technical meetings, conferences and other gatherings and distribute copies.

B. Typical Duties

Make notes of meetings, assemblies, conferences and other gatherings.

Prepare proper reports of proceedings of meetings.

Prepare distribution lists and see to necessary distribution.

Prepare letters of transmittal and proceedings and minutes.

Issue proper instructions to personnel for typing, constructing and reproducing subject matter, and follow up to assure prompt completion.

Collect supporting data for use in preparing reports of meetings.

Edit reports of Committees and Standards prepared by Committees.

Make arrangements for meetings, establishing time and place and notifying members.

Prepare agendas, questionnaires and related items, following up to assure final disposition.

Perform related duties as assigned.

Assist in answering technical inquiries received at A.W.S. Headquarters.

C. Detailed qualifications (Listed in order of importance)

1. Personality and Character: This is by far the most important aspect of any candidate's qualifications.

A candidate should be able to demonstrate by his past experience and personal references that he is capable of working with technical men at all levels in a cooperative manner. He must be capable of acquiring, in the course of about a year's time, an appreciation of the functions of A.W.S. Headquarters' Technical Staff in successfully dealing with technical committee personnel, A.W.S. members and the general public. Initiative and imagination, within reason, are very desirable requisites.

2. Experience: At least three, preferably five, years' experience in some kind of engineering work, preferably where working to standards and specifications was involved. (A familiarity with welding is desirable, but least essential of all qualifications.)

3. Education: A degree in engineering, any branch, from a recognized college or university. Active participation in extracurricular student activities would suggest an ability to acquire an appreciation of technical committee activities, so vital to success.

4. Age: 28 to 35 years. This range is suggested so that the candidate will possess sufficient maturity of judgment in dealing with technical committee personnel and others.

5. Salary: Salary commensurate with qualifications and experience.

Those interested in being considered for the position should submit a résumé of qualifications at once to S. A. Greenberg, Technical Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Such résumé should include information as to age, marital status, education, experience and other information which would be helpful in judging the suitability of the candidates.

WELDING RESEARCH COUNCIL

of the Engineering Foundation

Sponsored by the American Welding Society and American Institute of Electrical Engineers
American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers
American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to The Welding Journal, January, 1951

Welding Procedures for High-Pressure, High-Temperature Steam Piping

Development of welding procedures for alloys intended for high-temperature and high-pressure steam service including preheat and postheat treatments for various alloy combinations, electrode selection and thermal shock fatigue tests

by N. L. Navarre

INTRODUCTION

THE evolution of the present high-pressure, high-temperature steam system was accelerated tremendously during the past two decades. In the early thirties, temperature and pressure were approximately 440° F. and 400 psi., respectively. By the late thirties, most of the capital ships of our Navy had been modernized and were operating under 650° F. and 900 psi. steam conditions. Today, steam-generating systems operating at 1050° F. and 2000 psi. are under construction. Thus, over the span of a relatively few years we have seen reciprocating engines replaced by high-speed turbines and flanged connections replaced by welded joints. To satisfy the demand for steam generation at increased pressures and temperatures, new alloys had to be developed. For 650° F. steam service, carbon-molybdenum alloy steel was produced. The Springdale failure in 1941 resulted in the addition of chromium to carbon-molybdenum alloy steel for stabilization against graphitization at prolonged elevated temperature service. The demand for greater strength in the present-day steam systems is being met by still higher percentages of the alloying elements such as chromium and molybdenum, and in some cases by the use of austenitic steel.

The great strides taken in steam power systems could hardly have been possible without the scientific advances made in welding. Each new alloy introduced new problems which had to be solved before the fabricator could install the system. First, the electrode producers had to furnish electrodes that would yield weld metal with mechanical properties comparable to those of the base metal under the intended service conditions. Secondly, welding procedures had to be developed that would not impair the original properties of the base material. The mere fact that austenitic steel systems are being considered for high-temperature, high-pressure steam service brings to mind at least one problem requiring immediate solution to permit effective use of the applicable materials. This problem is the welding of joints comprised of materials having considerable difference in expansion coefficients, i.e., ferritic vs. austenitic joints.

The Navy has pioneered in the application of carbon-molybdenum steel piping and turbines for the 650° F. installations, which started in the late thirties. It is now pioneering in the application of new materials for steam generation at pressures up to 2000 psi. and temperatures up to 1050° F. The role of the Welding and Electrical Laboratory of the Experiment Station is to

N. L. Navarre is Welding Engineer, U. S. Naval Engineering Experiment Station, Annapolis, Md.

Presented at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

The views and opinions expressed by the author are not necessarily those of the Navy Department.

perform investigations and tests to develop welding procedures for new materials. This paper presents the development of welding procedures intended for the above given high-pressure, high-temperature steam service.

PRE- AND POSTHEAT TREATMENT DETERMINATION

The base materials employed in this investigation were as follows:

(*a*) $^1/_2$% chromium–$^1/_2$% molybdenum
(*b*) 1% chromium–$^1/_2$% molybdenum
(*c*) $2^1/_4$% chromium–1% molybdenum
(*d*) 4–6% chromium–$^1/_2$% molybdenum
(*e*) 18% chromium–8% nickel (columbium)

Each of the above materials was submitted to a synthetic weldability test* developed at the Experiment Station. In brief, this test consists of determining the relative notch toughness of the steels prior and subsequent to the application of a synthetic thermocycle of welding. Notch toughness is defined as the radius about which a $^3/_8$- x $1^1/_2$-in. bar, containing a specially designed notch at midlength, bends 180° without failure. The radius is given as a multiple of the specimen thickness. The synthetic thermocycle of welding is applied by heating a $^1/_2$-in. wide band, at midlength of the specimen, to 2150° F from room temperature in 49 sec. by high-frequency induction. The metallurgical changes produced are comparable to those which occur in the heat-affected zones of multiple pass manual arc welds. In the event the notch toughness of the steel is impaired by the application of this synthetic thermocycle of welding, treatments at various degrees of preheat and/or postheat are applied until a combination is found that permits the base material to bend around the original radius. Thus, the applicable treatments for materials given in Table 1 were determined without actual welding.

Stress Relief Temperature Determination

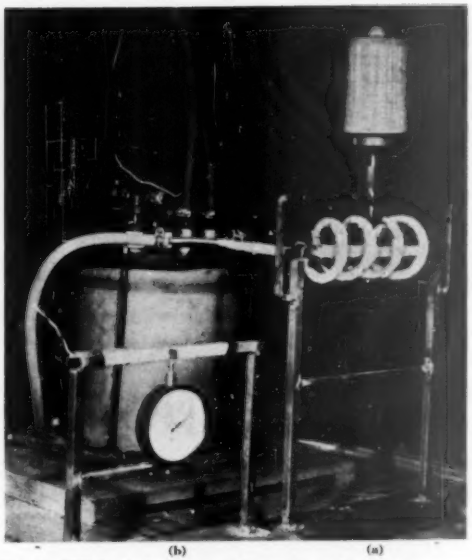
The performance of the high-frequency notched-bend test yields information which determines whether the metallurgical conditions in welded structures are satisfactory, particularly in regards to notch toughness.

* "A Method for Determining the Applicable Welding Procedure for Steels," Ronay Bela, THE WELDING JOURNAL, **25** (11), Research Suppl., 736-s to 747-s (1946).

Table 1—Preheat and Postheat as Determined by EES High-Frequency Notch-Bend Test

Material, %	*Preheat, ° F.*	*Postheat, ° F.*
$^1/_2$ Cr–$^1/_2$ Mo	300–400	1275–1300
1 Cr–$^1/_2$ Mo	400–500	1275–1300
$2^1/_4$ Cr–1 Mo	400–600	1300–1325
4–6 Cr–1 Mo	500–600	1300–1325, Cool to 900 and hold
18 Cr–8 Ni	None*	None*

* Test not applied to this material. Data included merely to complete tabulation.



(b) (a)

Fig. 1 EES loaded beam test for stress-relief temperature determination
(a) loaded beam in heating coil; (b) measurement of permanent set

However, previous experience with the 4–6% chromium–$^1/_2$% molybdenum type steel showed that the temperature applicable to obtain stress relief may vary considerably from that required to restore notch toughness subsequent to welding. Therefore, the applicable stress relief treatment was determined for each of the ferritic alloys given in Table 1. The procedure employed, Fig. 1, is somewhat qualitative but it has proved to be effective for the purposes intended. It employs a rectangular beam measuring approximately 0.3 x 0.4 x 11 in. as the test specimen. This beam, Fig. 1(*a*), is supported horizontally within a high-frequency induction coil and loaded at midlength to the maximum fiber stress of 3000 psi. Subsequently, the beam is heated by high-frequency induction, while under load, to a predetermined temperature level which is selected arbitrarily. The holding time at this temperature is approximately 20 min. After cooling to room temperature, the amount of permanent set is measured employing a dial indicator of 1/10,000 in. sensitivity, Fig. 1(*b*). In the event no permanent set has occurred, the procedure is repeated at increasingly higher temperature levels until a permanent set of approximately 0.015 in. is obtained. The temperature which produces this permanent set is then taken as the stress-relieving temperature of the metal, since at this temperature all stresses over 3000 psi. were relieved by plastic deformation. The stress-relief treatments obtained by the above method are given in Table 2. Examination of the data contained in this table revealed a stress-relief temperature of 1150° F. for 4–6% chromium–$^1/_2$% molybdenum, while the postheat treatment given for the same material in Table 1 is 1300–1325° F. followed by a

Table 2—Stress Relief Treatment as Determined by EES Loaded-Beam Test

Material, %	*Stress Relief Treatment,* ° F.*
½ Cr–½ Mo	1275
1 Cr–½ Mo	1275
2¼ Cr–1 Mo	1300
4–6 Cr–½ Mo	1150
18 Cr–8 Ni	None†

* Holding time to be 2 hr. per inch of metal thickness.
† Stress-relief temperature determination test not applied to this material. Data included merely to complete tabulation.

holding period at 900° F. This indicates that even though the former treatment is adequate to relieve residual stresses, it is not adequate to restore the original notch toughness of the material. Since it is obvious that the latter treatment will serve both purposes without changing the metallurgical structure of the material, it was selected as the proper postheat treatment for 4–6% chromium–½% molybdenum alloy steel.

Residual Stress Determination

The findings of the induction-heated notched-bend test were substantiated by actual welding tests. In order to ascertain the validity of the stress-relief treatment, stress analysis was performed for a welded 10 in. IPS Schedule 160 1¼% chromium–½% molybdenum alloy steel tube joint to which the applicable stress-relief treatment of Table 2 had been applied. The method of stress analysis employed for this purpose consisted of dissecting the assembly into 3-in. lengths and then relaxing each section by making a cut through one wall thickness. The resultant deflection was measured on tram points inserted along generator lines, in a plane perpendicular to that in which the saw cut is made. Subsequently, considering a quadrant of the tube as a curved beam fixed at one end and with a concentrated load at the other end, the stress is computed for a unit length of the tube section employing the following formula:

$$S = \frac{4EId}{R^2M}$$

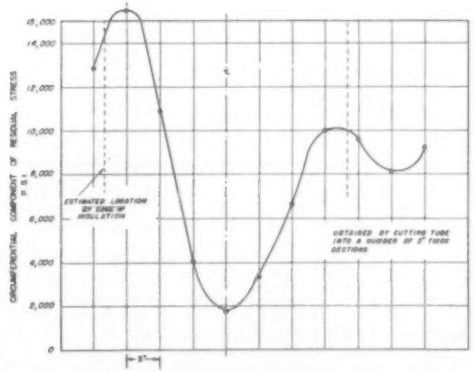

CIRCUMFERENTIAL COMPONENT OF RESIDUAL STRESS P.S.I.
ESTIMATED LOCATION OF END OF INSULATION
OBTAINED BY CUTTING TUBE INTO A NUMBER OF 3" THICK SECTIONS

Fig. 2 Results of stress survey by relaxation method

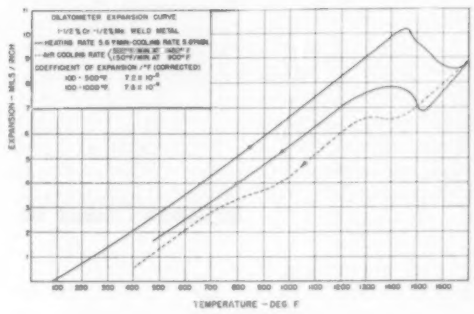


Figure 3

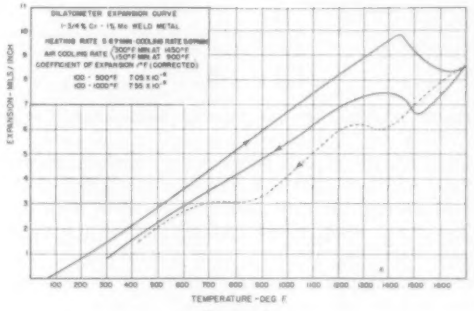


Figure 4

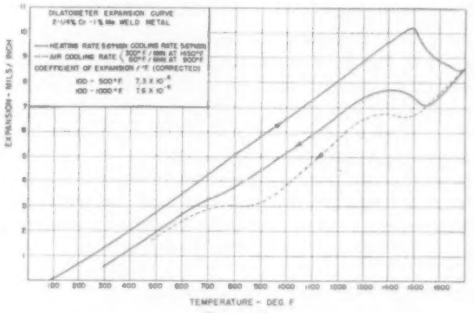


Figure 5

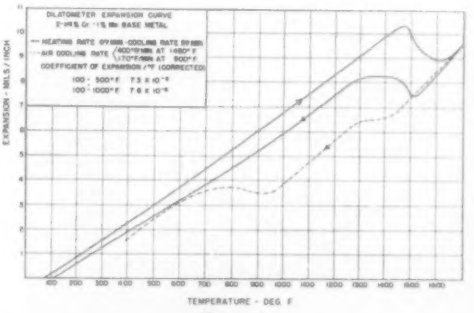


Figure 6

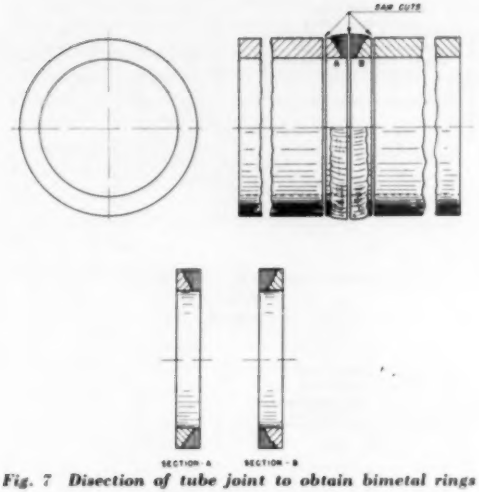


Fig. 7 Disection of tube joint to obtain bimetal rings

where S is the stress in psi., E is the modulus of elasticity, I is the moment of inertia of a unit length of the tube section, d is the deflection obtained for the quadrant of the tubing under consideration (change in diameter of tubing divided by two), R is the original mean radius of the tubing and M is the section modulus of a unit length of the tube section.

The results of the stress survey performed by the above described relaxation method for a welded 10 in. IPS 1¼% chromium–½% molybdenum alloy steel tube joint which was stress relieved at 1275° F. for 3 hr. are given on Fig. 2. Examination of these results indicate a negligible circumferential stress of 1750 psi. in the weld zone (center of stress-relieved zone). Accordingly, the stress-relief treatment of 1275–1300° F. is considered adequate to eliminate residual stresses. On the other hand, the unaffected portion of the tubing was found to have a circumferential stress as high as 12,000 psi. This condition indicates that the tubing as-received was not in the annealed, stress-free condition.

ELECTRODE DEVELOPMENT

Through the cooperation of electrode manufacturers, samples of various chromium-molybdenum alloy steel electrodes were made available for evaluation. Weld metal deposits from these electrodes were analyzed chemically for screening purposes. Then the electrodes were submitted to a usability test consisting of deposition in the vertical by means of an automatic welding head, thus eliminating the human element from the welding operations. The latter test furnishes information relative to the current range of the electrode, the arc stability of the electrode within this range and the uniformity of the burn-off rate throughout the length of the electrode. Materials which passed the above tests successfully were put through the complete test procedure which yields information as follows:

(*a*) Soundness of the weld metal as determined by radiography.

(*b*) Static mechanical properties of the weld metal at room temperature and at the intended service temperature.

(*c*) Stress rupture and creep testing of the weld metal at the intended service temperature.

(*d*) Dilatometry of the weld metal as compared to that of the base metal.

A summary of data obtained for numerous chromium-molybdenum alloy steel electrodes tested as outlined above, is given in Table 3. Dilatometric curves for the various chromium-molybdenum weld metals intended for 2¼% chromium–1% molybdenum base metal are given on Fig. 3–6.

Ferritic-Austenitic Weldments

The design of steam generation plants for operation at 1050° F may present the problem of joining austenitic to ferritic tubing. The problem lies in the fact that there is a considerable difference between the coefficients of expansion of the austenitic and ferritic materials employed. Therefore, tests were performed to

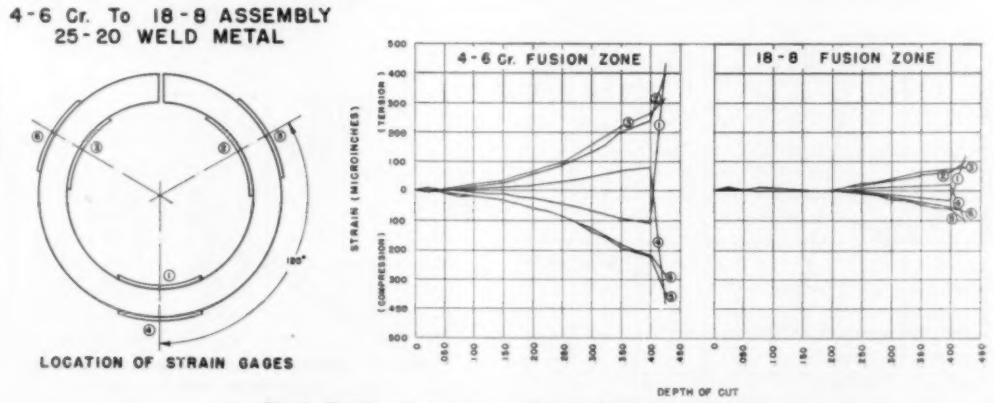


Fig. 8 Results of strain measurements during relaxation

determine residual stress values in composite joints between austenitic and ferritic tubing. The object of these tests was to select the optimum electrode for the purposes intended on the basis of minimum residual stress conditions in the weldment. For these tests, 4–6% chromium–½% molybdenum and 18% chromium–8% nickel tubing were employed to form four composite joints which were welded with each of the following electrodes:

(*a*) 25% chromium–20% nickel
(*b*) 19% chromium–9% nickel
(*c*) 25% chromium–12% nickel
(*d*) 15% chromium–35% nickel

Prior to welding, these assemblies were preheated 600° F. on the ferritic side and 400° F. on the austenitic side of the joint. These temperature levels represent the inverse ratio of the coefficients of expansion of the

Table 3—Results of Weld Metal Tests

BASE METAL CLASSIFICATION	ELECTRODE CLASSIFICATION	TYPE OF COATING	MECHANICAL PROPERTIES			
			T.S (psi)	Y.P. (psi)	ELONG. (%) 2"	RED. IN AREA %
1/2% Cr. - 1/2% Mo.	1/2% Cr - 1/2% Mo.	CELLULOSE	77,500 (1) TO 96,000 (1)	69,800 89,800	28.0 24.0	70.5 67.6
			54,300 (2) TO 69,000 (2)	37,000 52,500	24.0 16.5	64.9 57.8
1% Cr - 1/2% Mo.	1% Cr. - 1/2% Mo.	"	85,000 (1) TO 99,500 (1)	70,000 85,500	22.5 22.0	63.2 63.8
			63,500 (2) TO 77,000 (2)	48,100 65,500	26.0 21.5	66.8 60.6
2-1/4% Cr. - 1% Mo.	1-1/2% Cr - 1/2% Mo.	LOW HYDROGEN	86,700 (1) TO 91,000 (1)	68,100 78,000	26.0 23.0	69.3 59.5
			56,500 (3) TO 60,500 (3)	41,900 47,500	27.5 30.0	65.1 76.5
	1-3/4% Cr. - 1% Mo.	"	88,200 (1) TO 96,000 (1)	71,500 80,200	24.5 20.0	70.8 68.3
			55,500 (3) TO 61,800 (3)	42,400 51,500	24.8 18.0	64.8 36.0
	2-1/4% Cr - 1% Mo.	"	97,300 (1) TO 100,000 (1)	76,500 81,700	22.0 22.0	48.0 66.8
			57,000 (3) TO 59,200 (3)	40,500 43,200	26.0 21.0	76.2 74.6

ELECTRODE CLASSIFICATION	STRESS RUPTURE				CREEP		
	TEMP. °F.	STRESS (psi) TO CAUSE FRACTURE IN:			TEMP. °F.	STRESS (psi) FOR 1% MIN. CREEP IN:	
		100 Hrs.	500 Hrs.	1000 Hrs.		10,000 Hrs.	100,000 Hrs.
1-1/2% Cr. - 1/2% Mo.	1050	30,000	24,000	22,000	1050	10,000	5,000*
2-1/4% Cr. - 1% Mo.	1050	35,000*	24,000	20,000	1050	11,000	6,000
2-1/4% Cr. - 1% Mo. WROUGHT PIPE	1050	23,000	19,000	17,500	1050	12,000	6,500

(1) TESTED AT ROOM TEMPERATURE. *EXTRAPOLATED
(2) " " 950° F.
(3) " " 1050° F

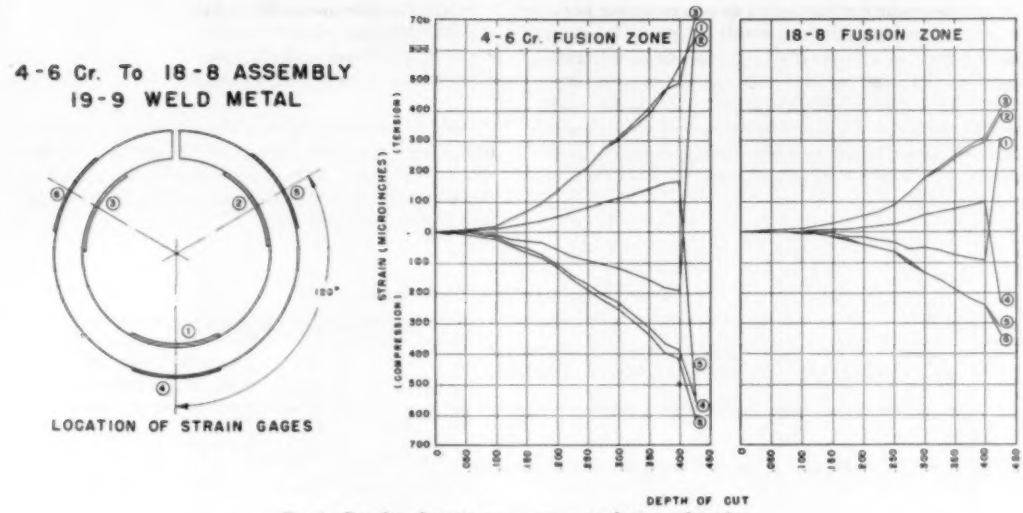


Fig. 9 Results of strain measurements during relaxation

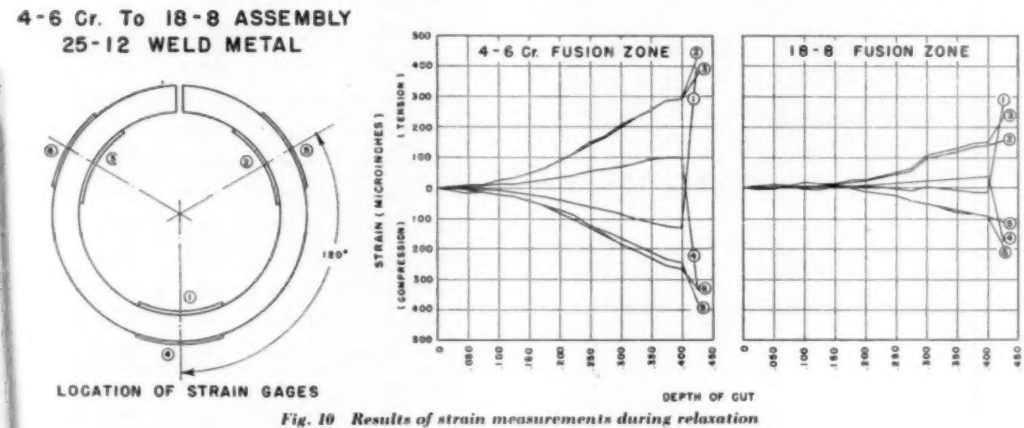


Fig. 10 Results of strain measurements during relaxation

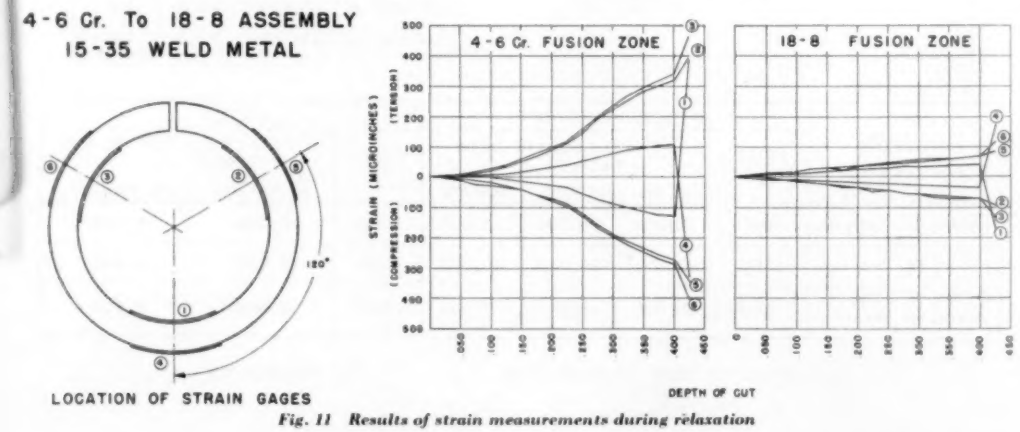


Fig. 11 Results of strain measurements during relaxation

components of the joint. Subsequent to welding, the assemblies were postheat treated as indicated in Table 1 for 4–6% chromium–$^1/_2$% molybdenum alloy steel. After cooling to room temperature, each of the tube joints was dissected as indicated in Fig. 7 to yield a bimetal ring from each fusion zone. Thus, four pairs of bimetal rings were obtained as follows:

(*a*1) 25% Cr–20% Ni weld metal vs. 4–6% Cr base metal

(*a*2) 25% Cr–20% Ni weld metal vs. 18% Cr–8% Ni base metal

(*b*1) 19% Cr–9% Ni + Cb weld metal vs. 4–6% Cr base metal

(*b*2) 19% Cr–9% Ni + Cb weld metal vs. 18% Cr–8% Ni base metal

(*c*1) 25% Cr–12% Ni weld metal vs. 4–6% Cr base metal

(*c*2) 25% Cr–12% Ni weld metal vs. 18% Cr–8% Ni base metal

(*d*1) 15% Cr–35% Ni + Cb weld metal vs. 4–6% Cr base metal

(*d*2) 15% Cr–35% Ni + Cb weld metal vs. 18% Cr–8% Ni base metal

All of the above bimetal rings were machined to the same outside and inside diameter and length. Then the rings were relaxed by making a longitudinal cut through one wall thickness in decrements of 0.025 in. Sr-4 strain gage readings were taken after each decrement and plotted against depth of cut. All of this work was performed in a constant temperature room. The results of this stress survey are given in Figs. 8–11. From these results, it is obvious that the weldment containing 25% chromium–20% nickel has the lowest order of residual stress. In view of the above, 25% chromium–20% nickel electrodes were selected for welding ferritic to austenitic tubing even though this type of weld metal has a definite tendency toward microfissuring. However, it was felt that this tendency could be minimized by careful control of the welding operations.

Fig. 12 - Thermal Shock Apparatus

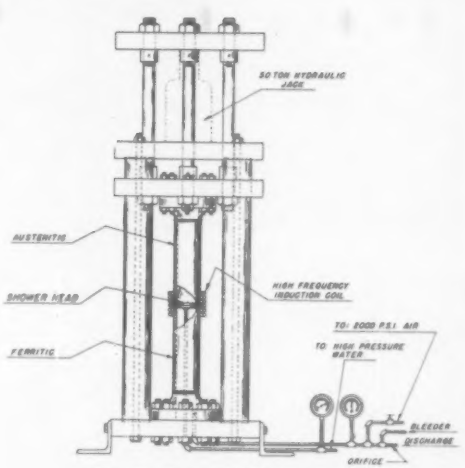


Fig. 12 Thermal shock apparatus

EVALUATION TESTS

In order to determine the applicability of the findings of the tests described in this paper for materials of equal coefficient of expansion, numerous tube joints were welded and tested. The results of the tests performed for these tube joints indicated that the welding procedures given in Table 4 for ferritic and austenitic materials, respectively, are suitable for the purposes intended.

The preliminary tests of the investigation concerned with the evaluation of the findings of the tests described herein for composite joints, comprising materials of dissimilar coefficients of expansion, employed means to develop thermal gradients of 800° F. in $2^1/_2$ sec. between the bore and outer surface of the tubing. For

Table 4—Welding Procedures

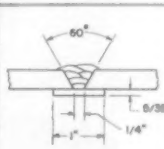
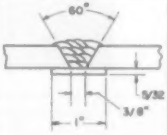
BASE METAL COMPOSITION	ELECTRODE COMPOSITION	TYPE OF COATING	JOINT DESIGN	PREHEAT AND INTERPASS TEMP.	CURRENT LEVEL	DEPOSITION TECHNIQUE	POST HEAT TREATMENT
1/2% Cr - 1/2% Mo. 1% Cr - 1/2% Mo.	1/2% To 1-1/4 Cr - 1/2% Mo.	CELLULOSE		400 - 500° F.	NORMAL CURRENT AT NORMAL ARC VOLTAGE	WEAVE UP TO 3 DIAMETERS OF ELECTRODE	1275 - 1300° F.
2-1/4% Cr. - 1% Mo.	1-1/2% Cr - 1/2% Mo. To 2-1/4% Cr - 1% Mo.	LOW HYDROGEN		400 - 600° F.	MAXIMUM CURRENT AT MINIMUM ARC VOLTAGE	"	1300 - 1325° F.
4-6% Cr - 1/2% Mo.	4-6% Cr - 1/2% Mo.	"		500 - 600° F.	"	"	1300 - 1325° F. COOL TO 900 AND HOLD
18% Cr - 8% Ni.	19% Cr - 9% Ni.	"		NONE	MINIMUM CURRENT MINIMUM ARC VOLTAGE	STRINGER BEADS	NONE

Fig. 13 Root condition subsequent to thermal shock in ferritic vs. austenitic tube joint welded with 25% Cr, 20% Ni electrodes. × 100

(a) Backing ring 2¼% Cr, 1% Mo; (b) ferritic 2¼% Cr, 1% Mo; (c) weld metal 25% Cr, 20% Ni and (d) austenitic 18% Cr, 8% Ni

this purpose, 4 in. IPS Schedule 160 tubing was used. In this part of the investigation, no internal pressure was applied. Having learned the method for developing the above thermal shock, a jig was designed for its application to a weldment pressurized to 2000 psi. This jig is shown schematically on Fig. 12. The test assembly is pre-stressed in tension to 12,000 psi. employing the hydraulic jack shown on top of the jig. Then the assembly is heated to 1050° F. in about 20 min. employing high-frequency induction heating. After holding for a sufficient length of time to obtain temperature saturation, the joint, while under pressure, is shocked from within with one pint of water. This pint of water, injected by means of the shower head shown on Fig. 12, produces a thermal gradient of approximately 800° F. between the outer periphery and the bore of the joint. A total of 20 such thermal shocks is applied during an 8 hr. day. Thereafter, the assembly is allowed to cool overnight developing the initial preset stress as room temperature is approached.

The first assembly tested in this manner was a ferritic (2¼% chromium–1% molybdenum) vs. austenitic (18% chromium–8% nickel) tube weldment containing a 25% chromium–20% nickel weld. After 300 thermal shocks, the assembly was removed for surface inspection and physical testing. The surface inspections performed for the assembly revealed nine fine cracks. Metallographic examinations performed for transverse weld specimens taken from the assembly revealed root cracks of the order shown on Fig. 13. This condition was evident in the results of bend tests. The above defects were not evident in a pilot assembly fabricated employing identical welding procedures. The latter assembly was tested without being exposed to thermal shocks.

In view of the above mentioned defects, a second 2¼% chromium–1% molybdenum vs. 18% chromium–8% nickel tube weldment was subjected to the thermal

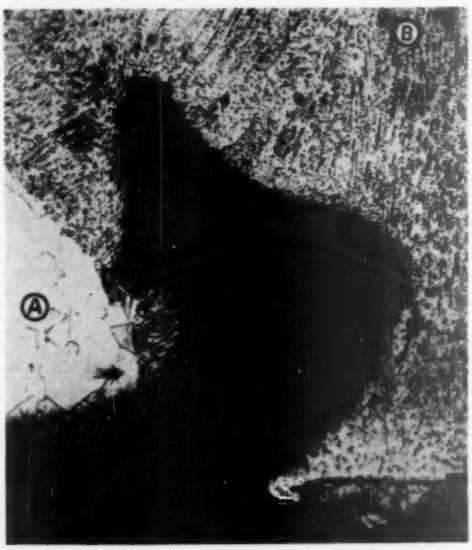


Fig. 14 Root condition subsequent to 30 cycles of thermal shock in ferritic vs. austenitic tube joint welded with 19% Cr, 9% Ni (Cb) electrodes. × 100

(a) Austenitic base 18% Cr–8% Ni; (b) weld metal 19% Cr–9% Ni (Cb)

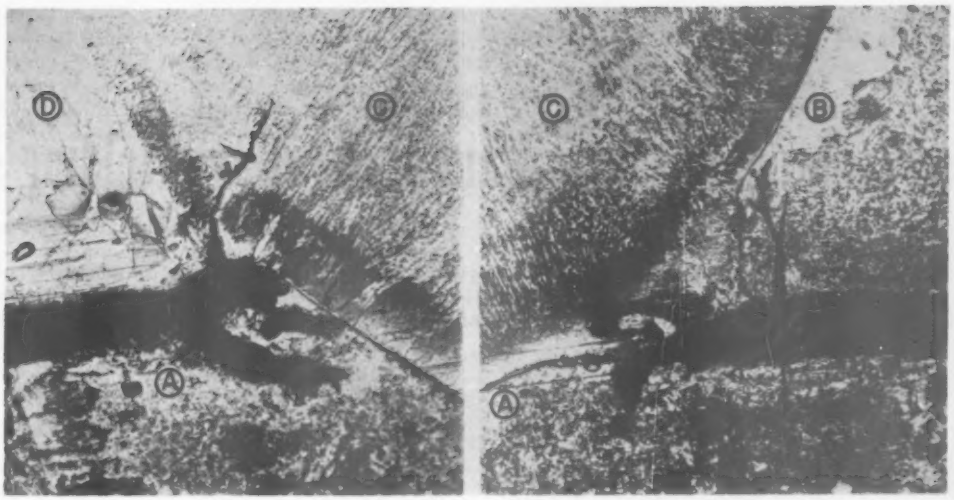


Fig. 15 Root condition subsequent to 600 cycles of thermal shock in ferritic vs. austenitic tube joint welded with 19% Cr, 9% Ni (Cb) electrodes

(a) Backing ring 2¼% Cr, 1% Mo; (b) ferritic 2¼% Cr, 1% Mo; (c) weld metal 19% Cr, 9% Ni (Cb) and (d) austenitic 18% Cr, 8% Ni

shock test described above. This weldment was fabricated employing 19% chromium–9% nickel plus columbium electrodes. After 300 thermal shocks, this assembly was found to be free of surface defects. However, a small transverse weld specimen removed by a weld prober was found to contain the root condition shown on Fig. 14. This condition has the appearance of a shrinkage cavity and is apparently local in character as the other side of the specimen was free of this condition. The distance between the two faces of the specimen examined was approximately ¼ in.

The volume removed by the weld prober from the above joint was replaced by welding and the assembly re-installed in the thermal shock jig. This assembly was subjected to another 300 cycles of thermal shock. At this time the root condition shown on Figure 15 was found. This condition was substantiated by the results of the root bend test.

SUMMARY

The above described program resulted in the development of welding procedures for the following alloy steel tubing wherein each alloy is welded to itself:

(*a*) ½% Cr–½% Mo
(*b*) 1% Cr–½% Mo
(*c*) 2¼% Cr–1% Mo
(*d*) 4–6% Cr–½% Mo
(*e*) 18% Cr–8% Ni plus Cb

Tests of composite joints between 2¼% chromium–1% molybdenum and 18% chromium–8% nickel steels wherein thermal shock is employed indicate that 19% chromium–9% nickel (Cb) weld metal is apparently more suitable for the purposes intended than 25% chromium–20% nickel. However, final conclusions concerning the suitability of these composite joints for use in high-pressure, high-temperature steam systems wherein the frequency and magnitude of thermal shock conditions are of prime importance, are being held in abeyance pending completion of considerably more research work in connection with this problem.

The author is indebted to Bela Ronay, Superintendent of the Welding and Electrical Laboratory at the U. S. Naval Engineering Experiment Station for his constructive review of this paper.

Rotating Electrode in Manual Metal Arc Welding

A holder was developed to facilitate striking the arc whereby the electrode is rotated thereby providing greater facility not only for striking but for maintaining the arc in metal arc welding

by Gilbert S. Schaller

MANUAL arc welding with a metallic electrode has been developed to the extent that both equipment and techniques have been subjected to but slight revision during the past several years. To be sure, electrode holders have not been standardized as to design; yet their operating principle remains unchanged in that they function by means of a clamped electrode. Clamping or holding methods are variable with the different designs; however the objective is the same with no apparent intention at modification being directed toward operating characteristics.

A somewhat similar situation exists in so far as electrode manipulation or methods of procedure are concerned. It seems altogether timely to note the lack of emphasis currently being given to this feature of welding. Welding proponents were formerly profoundly concerned with electrode manipulation. A review of the literature on this subject offers many examples of drawings and instructions on the movement or path of the electrode during welding. Such information served a useful purpose since, at that stage of welding development, there were few qualified operators and fewer trained supervisors. The entire situation was further complicated by the fact that electrodes had not been improved to the degree of excellence that is characteristic of those currently available.

Instructions for starting an arc with a metallic electrode include two distinct methods of procedure. In one, the electrode tip is brought into contact with the weldment in order to close the electrical circuit and then the electrode is withdrawn to form a suitable arc length. The second accepted method is that of scratching the electrode tip on the base metal with a motion that simulates that of striking a match. There are proponents of both of these systems and, in fact, modifications or combinations are used. Striking an arc poses no problem for the accomplished welder; however, the novice is confronted with the necessity of both striking and maintaining an arc. These requirements prove rather severe to the beginner and, not infrequently, cause him to discard welding entirely since his inability to strike an arc proves insurmountable.

This entire matter may seem inconsequential to management since there is a supply of experienced welders available to them. However, the problem reaches much deeper than merely the mechanics of arc manipulation when it is evaluated from the viewpoint of engineering education. The student who finds it difficult or impossible to master the technique of striking and maintaining an arc finds his patience tried to the point where he not only loses interest in welding but, what is much more serious, tends to develop an aversion to the entire subject of welding. Confronted with such circumstances, the instructor finds himself called upon to devote his time to detail that detracts from his effectiveness to teach welding as a method in contra-distinction to a skill. When emphasis must be placed on the latter, much of the desired objective is lost since manufacturing methods courses are designed, in our University, toward developing an appreciation of the potentialities of welding and not toward learning skills.

It was apparent that too much emphasis was being devoted to arc striking and manipulation at the expense of gaining fundamental knowledge of the welding process. The student was continually confronted with annoying frozen electrodes and its attendent variations. He was learning but little about arc action and electrode characteristics because of the distraction engendered by electrode sticking. In consequence, a solution was sought that would allay his recurring difficulties.

We had previously carried on some investigational work on the fire cracker type weld that was successful to the extent that sound, smooth welds had resulted. Our work did not extend beyond 3-ft. welds since we were unable to secure electrodes of greater length. Micrographs of such welds revealed excellent penetration and uniformly sound weld metal. The fact that arc length was uniform and of a magnitude governed by the thickness of the electrode coating, indicated the desirability of short arc lengths. The difficulty of starting an arc without freezing was one of the major problems. Several ideas were tried including such ex-

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pedients as affixing carbon tips to the electrode in a variety of arrangements. None of these devices yielded consistent results. The problem of starting the arc was satisfactorily solved by scarfing the electrode tip in a manner similar to the preparation for a lapped hammer weld. A thinned end presenting only a small amount of metal for initiating the arc, resolved the arc striking problem into a matter of routine.

With this background, experiments were directed toward the possibility of pointing a standard electrode as a means toward ameliorating the problem of starting an arc in manual welding. However, repeated experimentation did not yield the desired results. Electrodes froze because of a lack of movement or, stated differently, due to hesitation upon contact with the base metal. It was apparent from these observations that if the electrode were in continuing motion, there would be slight opportunity for it to stick on contact.

The solution to this difficulty was found by constructing an electrode holder equipped to rotate the electrode about its major axis. In common with new developments generally, several proposed designs were studied prior to constructing a working model. The initial one to be built is shown in Fig. 1. It proved to be entirely successful in so far as arc starting is concerned.

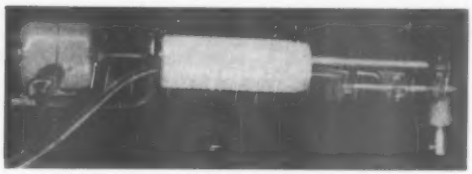


Fig. 1 Original model of electrode holder for rotating electrode

It may appear unweildy and cumbersome due to its apparent bulk; however, it is well balanced about its grip and does not seem to induce unusual fatigue even though it weighs $3^1/_4$ lb. Weight reduction to $2^1/_2$ lb. is possible through replacing steel components with light metals. A further weight saving can be made by exchanging the present motor with a smaller, lighter model.

The motor is a 6-v., d.-c. type equipped with a two-speed switch. Operating current is supplied by battery or rectification. The motor shaft extension is carried forward to a worm that meshes with a gear whose center coincides with that of the electrode. The driveshaft is housed in tubing that also functions as the frame for the holder A bracket serving as the motor base is brazed to the tubing. The grip is machined from thermosetting plastic whose bore carries a wooden insert. The latter has two longitudinal holes, one for the tubular frame and the other for the welding lead wire from the welding machine. A press fit between the tubular frame and the grip ensures necessary rigidity and alignment.

A copper assembly at the front serves as the current carrying member and housing for the worm gear drive.

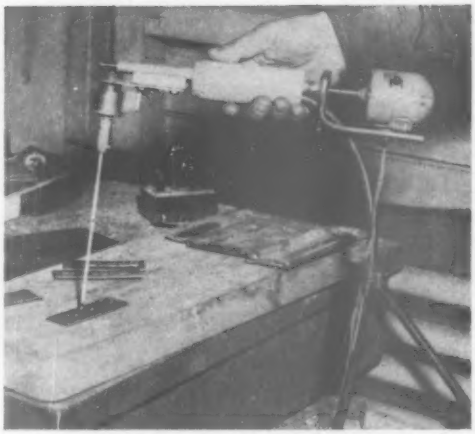


Fig. 2 Revised and currently used model

In the present models, the gear reduction supplies electrode rotative speeds of either 110 or 69 rpm. with the two-speed motor. Difficulty was experienced in the current carrying component because of a graphite bushing located inside the housing. Calculations indicated this bushing was too small for carrying large amperages but, since it was concealed within the housing, there was strong sentiment toward using the design because of its clean-cut appearance. Only a few trial runs were necessary to reveal the inadequateness of this construction.

A revised design as shown in Fig. 2, was developed to overcome the current carrying difficulty. The sole revision was that of placing a carbon brush and contactor on the lower side of the frame. The brush contacts a copper cylinder that is $1^1/_4$ in. in length and of approximately the same diameter. A tube of $^1/_8$ in. bore is brazed to this copper cylinder. This tube serves as a receptacle for the welding electrode. No attempt has been made toward developing a self-centering chuck as a replacement for the present holder. Some such device is indicated since it is imperative that the electrode be held in a concentric position with respect to the axis of rotation.

The only shortcoming of the apparatus in its present state of development is the necessity for mounting the electrode in truth and the further requirement that the electrode be straight. Failure in either of these requisites will result in an irregular path being traced by the electrode tip. When opportunity permits, it is intended to investigate the possibility of developing a mechanism that will give controlled movement to the electrode as required, by way of example, for a fillet weld. This is an intriguing possibility. Other modifications can take the form of mounting multiple electrodes in a variety of arrangements—there remains ample investigational work before the full potential of the rotating electrode is fully exploited.

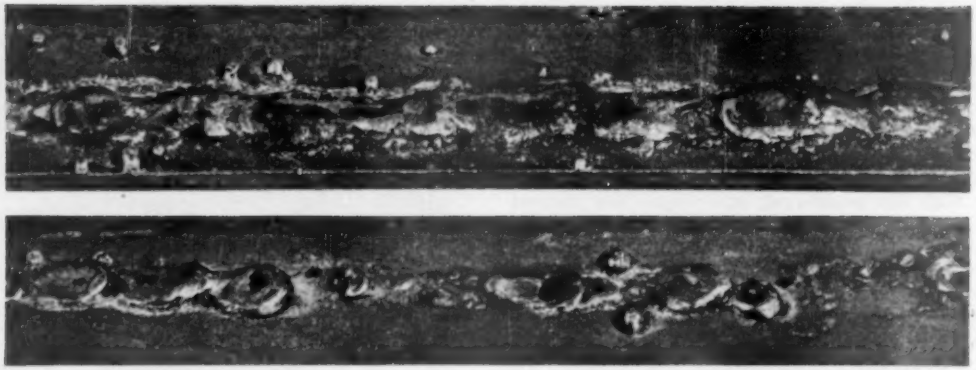


Fig. 3 Bead weld, first attempt by a novice. Rotating electrode in upper view and conventional method in lower view

EXPERIMENTAL APPLICATIONS

The motivation for developing the rotating electrode was that of providing equipment that would enable an inexperienced operator to perform a welding operation with a minimum amount of training. In order to study the functioning of this equipment, a generous number of test runs were made. The operators selected for these tests were, in every case, without any experience in arc welding. They were given the rotating electrode for their first attempt, and were asked to make the same weld with conventional equipment. A typical series resulting from these trials are seen in Fig. 3. This particular attempt at welding was made by a janitor who had not been given any instructions on welding, and who had never observed an arc in action.

The welding machine was set for 90 amp., and the electrode used for the test was an E-6010, $^1/_8$ in. diameter. The weld was made in the flat position and was a bead type on a strip of $^1/_8$- x $1^1/_2$-in. flat mild steel. Obviously inexpert results were to be expected from the test. However, in the case of the rotating electrode, a continuous deposit of weld metal was achieved. There appeared to be no difficulty in either kindling or holding the arc and no frozen electrode trouble developed throughout the test run. The operator failed to realize that as the electrode was consumed, the arc length would become excessive. In his attempt to shorten the arc, he frequently shorted the electrode on the base metal. This erratic manipulation explains the poor appearance of the bead in the upper view of Fig. 3.

Upon completion of the test run with the rotating electrode, the same operator attempted a similar weld using conventional equipment with the same electrode type and current value. The results of that trial run are shown in the lower view in Fig. 3. He encountered great difficulty in attempting this second weld. Striking the arc proved provocative as did the recurring loss of the arc. The operator remarked that he could not see what was taking place at the arc, where as with the rotating electrode it was possible to clearly observe the arc behavior.

A second series of test welds were made by this operator in which the welding current was increased to 95 amp. as a means of providing easier arc striking for the conventional welding. The results of these tests are shown in Fig. 4. No improvement is shown for either method, although here again, the rotating electrode, upper view, gave a continuous weld in contrast to the one produced by conventional equipment.

Parallel results have been achieved by students in the welding laboratory. Their efforts are generally more rewarding due, in large part, to their general knowledge of arc behavior and arc welding. They invariably comment on the fact that when welding with the rotating electrode, they can observe arc behavior and understand welding phenomena. While our work is inconclusive, there are strong indications that the novice whose initial training is with the rotating electrode, can master arc-welding techniques in a relatively short period. After he has spent as little as an hour's time with this equipment, he can proceed to conventional welding without the necessity for lengthy training on arc manipulation. This feature of the rotating electrode recommends its serious consideration for any training program where the element of time is important.

The rotating electrode equipment has been used by experienced welders in an endeavor to evaluate its potentialities for improving their abilities. Results from such tests are inconclusive—a condition that is to

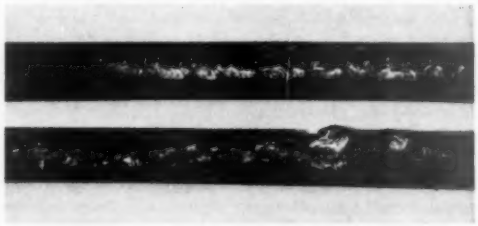


Fig. 4 Bead weld, second attempt by a novice welder. Rotating electrode in upper view and conventional method in lower view

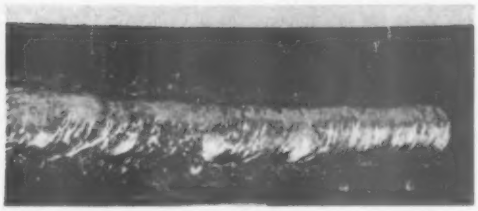


Fig. 5 Bead weld made by an accomplished welder using conventional equipment

be expected since, in effect, they are being asked to modify their skills which is a stringent assignment at best. A random example of a bead on plate test weld made by an accomplished welder can be seen in Fig. 5. This weld was made with conventional equipment employing 90 amp. and an E-6010, 1/8-in. diameter electrode on a strip of mild steel having a thickness of 1/8 in.

A specimen weld under the same conditions excepting that a rotating electrode was used is pictured in Fig. 6. The bead shows some irregularity when compared to conventional welding. It might be well to note, however, that in this case, the trained welder was being called upon to learn a new skill and that he had not mastered the new equipment. This line of testing has not been pursued to any extent in as much as there appear to be more interesting fields of application for the rotating electrode principle.

One fact has emerged from our work with the rotating electrode. We are certain that welds made with this equipment do not require the same amount of welding current as does conventional welding for the same conditions. Since our experimental apparatus can accommodate only 1/8-in. diameter electrodes, the test data has been compiled for only that one size. Consistently sound welds are made with lower current values than those generally employed for a 1/8-in. electrode. These welds have been examined microscopically as well as mechanically by every recognized standard test. Welds made with conventional equipment and the lower current values did not yield results approaching those of the rotating type.

In an endeavor to further prove this, one series of tests was directed toward developing the minimum current values that could be used successfully with a 1/8-in. diameter electrode. During this experiment welds were made with successively diminished current values until 18.5 amps were reached. Welds could not be made satisfactorily at that low current due to the fact that the electrode coating failed to fuse. It is interesting to note that irrespective of minimum current, a very short arc could be maintained without experiencing any difficulty from sticking the electrode and extinguishing the arc.

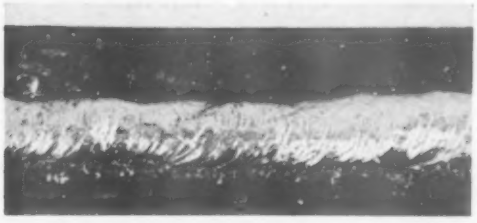


Fig. 6 Bead weld made by an accomplished welder using the rotating electrode

This feature of the rotating electrode is deserving of much more than passing consideration. The short arc is conducive of sound weld metal. Oxidation is minimized as is nitride formation. Sufficient evidence is lacking to suggest that hydrogen pickup would be affected; yet such an assumption cannot be completely discarded.

Another favorable feature results from the fact that the operator is freed from giving attention to minimum arc lengths. He need not be concerned with arc extinction and, in consequence, can concentrate his efforts in the direction of correct manipulation. Obviously, some training is indicated for the experienced welder since he must revise his skill; yet all of those who have welded with the rotating electrode have been enthusiastic over its operational characteristics.

A profound economic implication develops when consideration is given to the fact that larger than traditional sized electrodes can be employed for a given weld. The larger electrode has a greater weld metal potential than the smaller one. If then, a larger electrode is used, more welding can be accomplished between electrode changes than in the case of the usual size. Test results indicate that the larger electrode will not require as much current when used rotatively as in conventional application. Integration of these two aspects of the rotating electrode indicates a substantial economic saving in its favor.

Welding Sheet Metal

In an endeavor to prove that low current values could be used successfully with oversized electrodes, a series of tests for welding galvanized sheet steel were initiated. It was believed that galvanized sheet would offer the most severe test in as much as excessive heat will cause undue deterioration of the coating on the sheet.

In this series of tests, E-6013 electrodes of 1/8 in. diameter were employed throughout. Butt welds were made in every case without a backing strip being used. Test welds were started on 14 gage sheet, a size that was welded satisfactorily by both methods with a current setting of 70 amp. These welds were followed by 16 gage at 65 amp., and they by 18 gage at 40 amp. On the latter, some difficulty from melting through was observed with conventional welding. When welding 20 gage sheet, it was found necessary to employ 35 amp. for the conventional method in order to maintain an arc. Welding results were inconsistent and overheating was in evidence. A current setting of 30 amp. was sufficient for the rotating electrode and satisfactory welds

were consistently made on 20-gage material.

Testing was continued with lighter gages but it was impossible to produce satisfactory welds with an $^1/_8$ in. diameter, E-6013 electrode by conventional equipment whereas the rotating electrode produced sound, acceptable welds. The lightest metal that could be welded with this electrode size proved to be 28 gage (0.0149 in.) with the use of 17 amp. Difficulty was experienced here because the electrode coating did not melt sufficiently rapid, resulting in evidence of improper shielding. Examination of Figs. 7–10, will indicate the appearance of the welding by both methods on 28-gage galvanized sheet metal.

Figure 7 is the top side of a butt weld and Fig. 8 is the reverse side of this weld.

The weld in the figures was made with a rotating electrode $^1/_8$ in. diameter at a current setting of 17 amp.

Figure 9 is the top side of a butt weld and Fig. 10 is the reverse side of this weld.

The weld in these last two figures was made by using conventional equipment; however, it was found necessary to increase the welding current to 35 amp. in order to maintain an arc. Indications of current values being too great for this light gage material is readily noted from the photographs. The results are so inferior that they cannot be dignified by being termed welds. This test series did serve the purpose of proving that lower current values can be used satisfactorily with rotating electrodes.

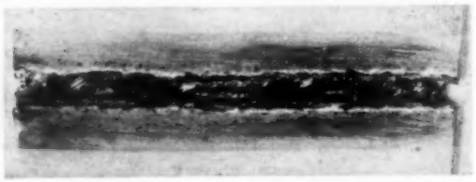


Fig. 7 Top side of butt weld on 28-gage, rotating electrode

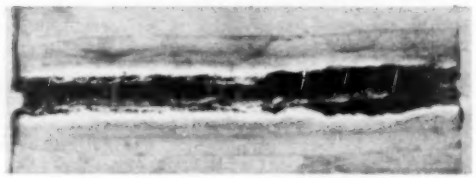


Fig. 8 Reverse side of butt weld in 28-gage, rotating electrode

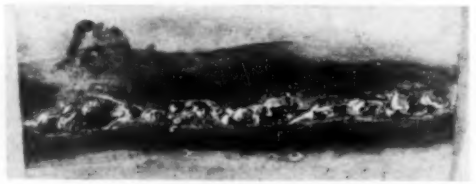


Fig. 9 Top side of butt weld in 28-gage, conventional welding

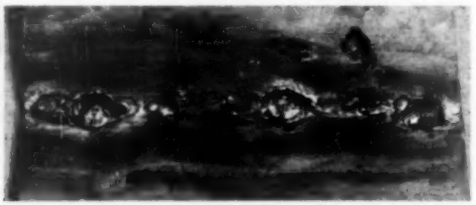


Fig. 10 Reverse side of butt weld in 28-gage, conventional welding

CONCLUSIONS

Rotating electrode equipment is without precedent and, as a result, a far more elaborate testing program is necessary in order to provide irrefutable conclusions. Undoubtedly further refinement of the equipment will improve its functionality and broaden its utility. Some slight inconsistencies in the welding results obtained, are traceable to shortcomings of the equipment. The design of the contactor elements requires revision in order to eliminate the tendency toward arcing that develops there at the upper speed of rotation. A reduction in bulk of the equipment as mentioned earlier, is another desirable revision.

Regardless of any shortcomings the apparatus may have in its present state of development, it has distinguished itself in three categories:

1. An inexperienced operator can do better welding with the rotating electrode than he can with conventional equipment. He learns arc manipulation with less training through the use of the rotating electrode.
2. Lighter gage sheet metal can be welded with the rotating electrode than is possible with conventional equipment where the same diameter electrode is employed in both cases.
3. The rotating electrode welds satisfactorily with less current than conventional equipment for the same electrode size and the same type weld.

Other fields of investigation for this novel equipment include such items as submerged arc welding, welding nonferrous metals and stainless steels. Then, too, as suggested earlier, a modified movement other than simple rotation or the use of two or more electrodes simultaneously can be expected to yield further interesting results.

The author wishes to acknowledge the profoundly valuable advice given by his colleague Prof. W. A. Snyder throughout the experiments with rotating electrodes. Two senior students, in Mechanical Engineering, E. C. Wicks and L. B. Zylstra are accorded my genuine thanks for their assistance in both the building of the apparatus as well as performing much of the routine test work.

Welding High-Temperature Austenitic Steel Piping

Balancing the composition of weld deposits in austenitic steel piping suitable for high temperature central station service. Sigma phase and microcracks

by R. W. Emerson and Matthew Morrow

INTRODUCTION

The need for the use of piping materials having higher load-carrying ability to withstand the increasing temperatures being employed in modern central stations today has, in several instances, led to the use of the austenitic 18% chromium – 10% nickel columbium grade (A.I.S.I. Type 347) of stainless steel. Whereas the $2^1/_4$ or 3% chrome – 1% moly ferritic steels are suitable and have been used for 1050° F. steam service, the use of the austenitic stainless grades, although initially more costly, results in a net reduction in wall thickness of approximately 40% of that required when using the ferritic grades at 1050° F.

In the fabrication of the austenitic materials, problems are encountered particularly in welding, which are entirely unlike those found in the welding of the ferritic material, and special care must be taken to avoid such difficulties.

Two of the problems encountered, the subject matter of this paper, are "sigma phase" and "microcracks."

SCOPE

This paper covers the results obtained on three welds made in $8^5/_8$ in. outside diameter by 1 in. wall forged and bored Type 347 material, one of which was welded manually, and two of which were welded using the submerged-arc process.

The manually deposited weld was made with a 19–9 cb (chrome-nickel-columbium) electrode which was properly balanced to produce a small percentage of ferrite in the as-deposited weld. The physical properties of this weld were found to be satisfactory in both the as-welded and stabilize-annealed condition.

One of the two submerged-arc welds was welded using an unbalanced high-chrome-nickel-columbium (29–9 cb) electrode and the other deposited with a standard 19–9 cb electrode. It was postulated that the weld having a higher chromium content would contain a considerable amount of ferrite which, although favorable in the prevention of microcracks, would have a deleterious effect on the weld deposit after a stabilize-anneal heat treatment or in the as-welded condition followed by years of service life in elevated temperature service (1050–1250° F.). Upon reheating austenitic material containing ferrite, the magnetic ferrite is transformed to a nonmagnetic, brittle constituent known as "sigma" which markedly lowers the ductility of the weld deposit. This weld was found to have excellent ductility in the as-welded condition and extremely poor ductility after a 1600° F. stabilizing heat treatment.

It was postulated that a sufficient loss in chromium would occur in the submerged-arc weld made using the 19–9 cb electrode so that the weld deposit would be nearly, if not fully, austenitic and that this weld would, therefore, develop microcracks. This weld was found to contain a large number of interdendritic cracks of both micro and macroscopic dimension.

CHEMISTRY OF MATERIALS USED

The chemical analyses of the forged and bored pipe (base metal), submerged-arc electrodes and deposit analyses of the three test welds are given in Table 1. Further comments on the chemistry of the weld deposits will be made during subsequent discussions of the results obtained on the physical properties of the test welds.

WELDING PROCEDURE

All joints were made using a standard A.S.A. B-31 "U" bevel having a 40° included angle, a $^3/_{16}$-in. radius adjacent to the root of the weld, a $^1/_{16}$-in. lip and a root opening of $^3/_{16}$-in. All joints were fitted with a $^3/_4$- by $^3/_{16}$-in. thick flat back-up ring of the same analysis as the pipe being joined.

R. W. Emerson is Metallurgist and **Matthew Morrow** is Asst. Metallurgist, Pittsburgh Piping & Equipment Co., Pittsburgh, Pa.

Presented at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

Table 1—Chemical Analyses of Materials

Test No.	*Material analyzed*	*C*	*Mn*	*Si*	*P*	*S*	*Cr*	*Ni*	*Cb*
1, Manual (19–9 Cb)	Weld deposit	0.066	1.72	0.56	0.016	0.011	19.40	10.41	1.04
	Base metal	0.06	1.81	0.24	0.017	0.016	18.74	10.74	0.95
2, Submerged arc (29–9 Cb)	Electrode	0.064	1.58	0.85	0.017	0.010	27.01	9.92	1.28
	Weld deposit	0.065	1.78	1.18	0.022	0.017	23.82	10.22	0.93
	Base metal	0.06	1.63	0.32	0.016	0.012	17.47	10.76	0.89
3, Submerged arc (19–9 Cb)	Electrode	0.061	1.66	0.66	0.019	0.012	19.14	10.30	1.24
	Weld deposit	0.066	1.96	1.00	0.024	0.012	18.14	10.84	0.88
	Base metal	See tests Nos. 1 and 2							

The manual weld (test No. 1) was placed in the fixed horizontal position and welded from bottom to top using six passes of $^1/_8$-in. and four passes of $^5/_{32}$-in. diameter lime-coated 19–9 cb electrodes. Somewhat contrary to normal procedure, a complete weave bead was used throughout. No preheat was used in making this test and the maximum interpass temperature did not exceed 300° F.

The submerged-arc 29–9 cb weld (test No. 2) was placed in a manipulator and roll-welded using 20 passes of $^5/_{32}$-in. diameter bare 29–9 cb electrode and 20 x 200 mesh No. 80 flux. The weld was made with a current of 375–400 amp. at 30–32 v. No preheat was used but the interpass temperature continued to rise during welding and was estimated to exceed 900° F.

The submerged-arc 19–9 cb weld (test No. 3) was made under the same conditions as that of test No. 2 except that bare 19–9 cb wire was used, and the granulation of the flux was 12 x 65 mesh. As a matter of interest, but having no particular bearing on this investigation, was the fact that the pipe ends were hot-upset prior to making this weld test.

MECHANICAL PROPERTIES OF TEST WELDS

In so far as was possible the mechanical testing of the welds was carried out in accordance with the requirements of Section IX, A.S.M.E. Boiler Construction Code. All joints were radiographed prior to mechanical testing and the individual test coupons in most instances were given a Zyglo examination.

Manual Weld (Test No. 1)

Radiograph and Zyglo examination of Test No. 1 indicated the weld to be of good sound quality. The side bend, free bend and tensile specimens from this weld are shown in Fig. 1, together with the tensile strength and elongation results obtained. The low elongation obtained in one of the free bend specimens was due to the weld being slightly off center together with evidence of a small tear at the fusion line of the specimen. It is to be mentioned, however, that both free bend specimens exceeded the 25% elongation required of such specimens not having had a stress-relief anneal or postweld heat treatment.

The macrostructure of the welded joint, also in the as-welded condition is shown in Fig. 2. The hardness of the base metal was found to average 145 and the weld deposit 220 Brinell.

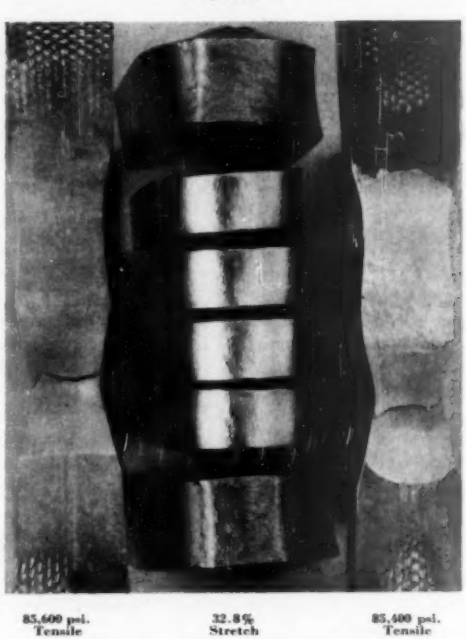


Fig. 1 As-welded side bend, free bend and tensile specimens removed from 8$^5/_8$-in. O.D. x 1-in. wall forged and bored Type 347 stainless pipe. Manually welded with lime Type 19–9 cb electrodes (test No. 1). 0.5×

Submerged-Arc Weld (Test No. 2)

The submerged-arc weld made using the 29–9 cb welding electrode was radiographed and the test coupons given a Zyglo examination. The results of

Fig. 2 As-welded macrosection from weld test No. 1. 1 ×

Fig. 3 As-welded side bend specimens (test No. 2) removed from 8⅝-in. x 1-in. wall forged and bored Type 347 stainless pipe. 1 ×. Welded by submerged-arc process using 20 x 200 No. 80 flux. Electrode, 29–9 cb

these tests indicated this weld to be likewise of good sound quality as was test No. 1. Figures 3, 4 and 5 show, respectively, the side bend, free bend and tensile specimens removed from this test. It is to be noted that the weld in each of these test coupons appear to be without flaw. It is to be noted from Fig. 4 that the free

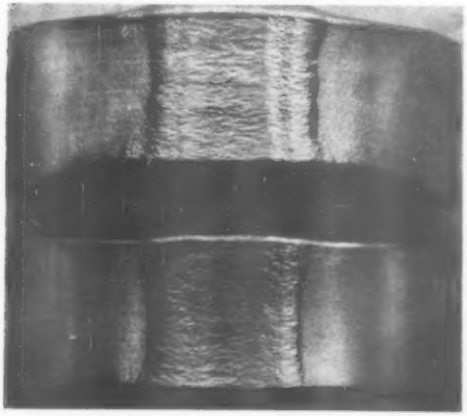


Fig. 4 As-welded free bend specimens (test No. 2) having 29% elongation. Bending continued to 35% before failure 0.85 ×

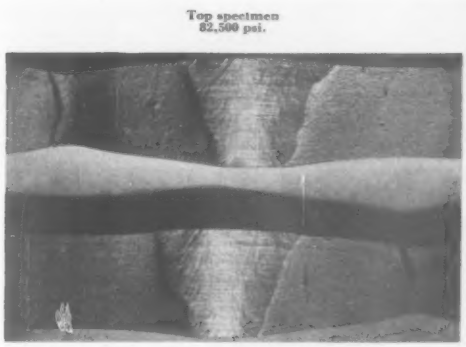


Fig. 5 Reduced section tensile bars (as-welded) from test No. 2. 0.85×

bend tests each have an elongation across the weld of 29% but that these bars were subsequently flattened further until failure occurred at an elongation of 35%. These values were, as those of test No. 1, in excess of the 30% required by Section IX, A.S.M.E. Code for welds which have been given a postweld heat treatment although the coupons were tested in the as-welded condition.

The macrostructure of this joint is shown in Fig. 6. The dilution effect is clearly visible in the root pass. The average Brinell hardness of the base metal was the same as in test No. 1 and the weld deposit was noted to be only slightly higher than test No. 1 (230 Brinell).

Submerged-Arc Weld (Test No. 3)

The submerged-arc weld made using the 19–9 cb welding electrode was radiographed and found to contain a continuous series or network of circumferential cracks of a most serious magnitude. Although the major cracks were of such dimensions that Zyglo examination was not needed, this test did reveal many smaller cracks which were less visible to the unaided eye. The extent of the cracking which occurred was such that it was not considered worth while to make mechanical tests on this weld.

Three macrosections at various locations around the joint are shown in Fig. 7. From these photographs it may be seen that, in addition to several major cracks

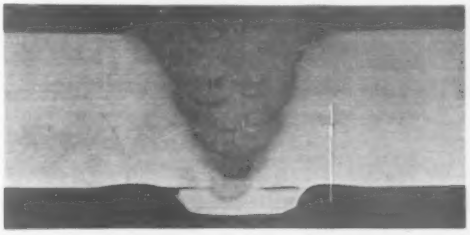


Fig. 6 As-welded macrospecimen from weld test No. 2. 1 ×

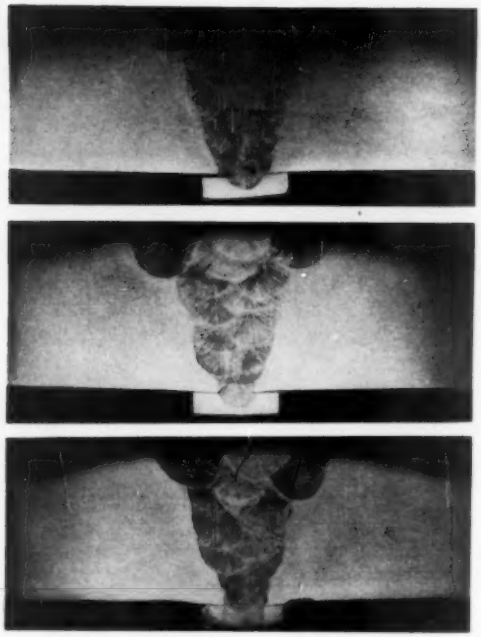


Fig. 7 As-welded macrosections (test No. 3) removed from 8⅝ in. O.D. x 1-in. wall (upset to 1 5/16-in. wall) forged and bored Type 347 stainless pipe. Welded by submerged-arc process, using 12 x 65 No. 80 flux. Electrode 19-9 cb −3/4×

which appear, numerous "microcracks"[*] throughout

(Top) 47.7% stretch

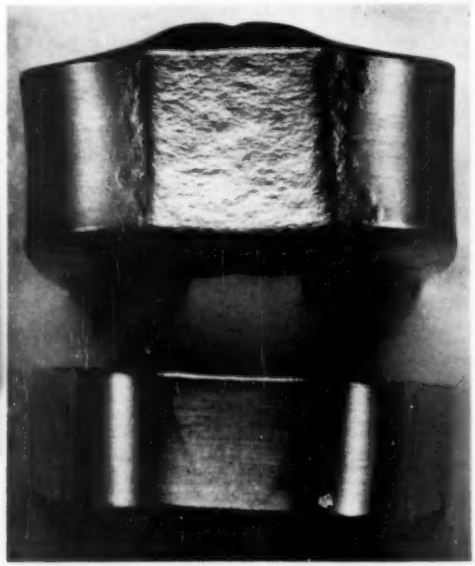
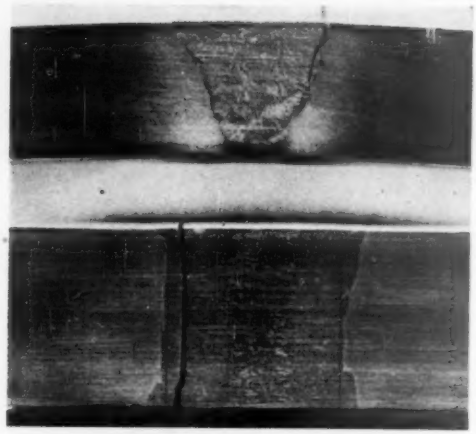


Fig. 8 Free bend and side bend specimen from test No. 1 after a stabilizing anneal (1600° F., 2 hr., air cool) heat treatment. 1 ×



3% Stretch

Fig. 9 Free bend and side bend specimen from test No. 2 after a stabilizing anneal (1600° F., 2 hr., air cool) heat treatment. 1 ×

the weld cross section are evident. The average hardness of this weld deposit was found to be 190 Brinell.

THE EFFECT OF STABILIZING HEAT TREATMENT ON MECHANICAL PROPERTIES

When fabricating welded pressure vessels of austenitic materials to A.S.M.E. U68 Construction, stress reliev-

[*] Owing to certain confusion in terminology and thought as to what constitutes a microcrack in so far as the term is applied to weld deposits of austenitic stainless steel, the authors define microcracks as those cracks which appear to originate and terminate at random, are relatively tight and do not exceed 1/8 to 3/16 in. in length in the plane of examination, are surface or subsurface with respect to the finished joint and are normally of such size and orientation that individually they are not readily detected by conventional radiographic technique.

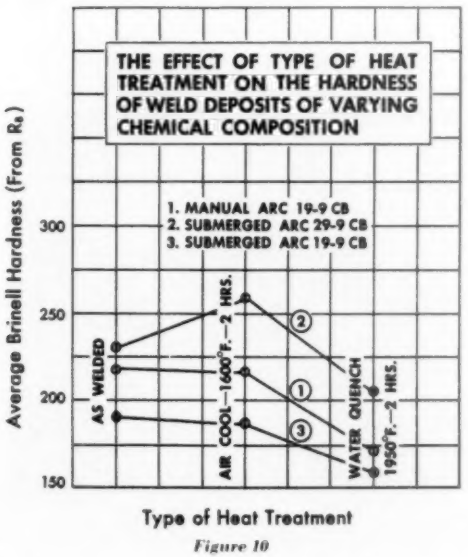

THE EFFECT OF TYPE OF HEAT TREATMENT ON THE HARDNESS OF WELD DEPOSITS OF VARYING CHEMICAL COMPOSITION
1. MANUAL ARC 19-9 CB
2. SUBMERGED ARC 29-9 CB
3. SUBMERGED ARC 19-9 CB
Average Brinell Hardness (From Rb)
300
250
200
150
AS WELDED
AIR COOL—1600°F.—2 HRS.
WATER QUENCH 1950°F.—2 HRS.
Type of Heat Treatment

Figure 10

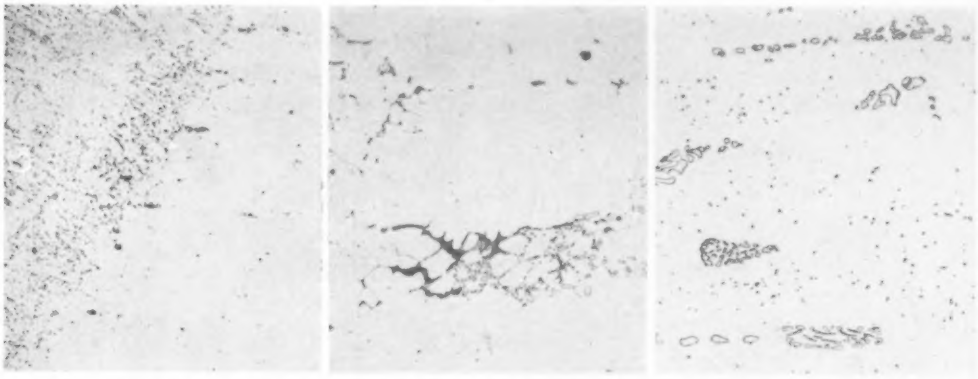
ing of the vessel must be accomplished at a temperature of 1300° F. minimum and in the case of Type 347 may be given a stabilizing heat treatment at 1550–1600° F. Higher temperatures may be used, but are normally avoided if possible.

This being the case, additional coupons were removed from weld tests Nos. 1 and 2 which were originally tested in the as-welded condition, and given a heat treatment of 1600° F. for 2 hr. followed by air cooling. Figures 8 and 9 show, respectively, a free bend and side bend test from test welds Nos. 1 and 2. Although both tests indicated satisfactory performance in the as-welded condition Figs. 8 and 9 show a striking difference in the performance of these two welds after heat treatment. Whereas a 180° bend having a weld metal elongation of 48% was obtained on the free bend from test No. 1, 3% elongation and a total bend angle of approximately 15° was obtained from test No. 2.

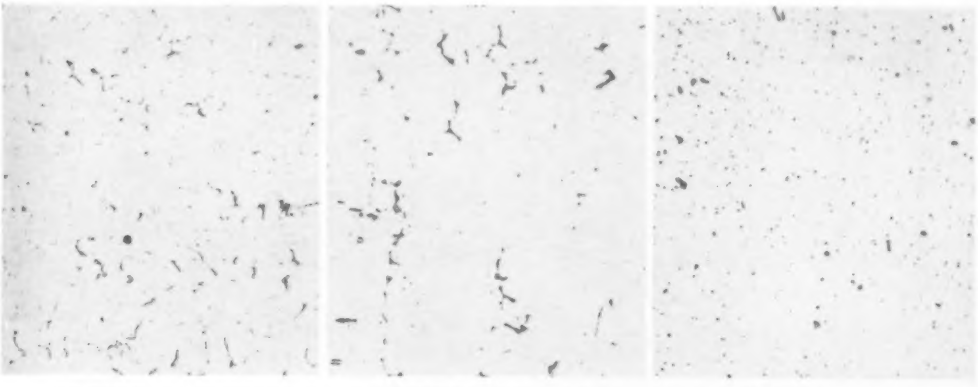
Whereas the heat treatment caused a slight drop in weld metal hardness over the as-welded condition of test No. 1, the hardness of test No. 2 increased from 230 to 258 Brinell. This, coupled with the fact that a distinct loss in magnetism had occurred, was considered conclusive evidence of the presence of "sigma phase." This same treatment was given to a section of test No. 3 and the hardness decreased only slightly from that of the as-welded specimen.

THE EFFECT OF QUENCH ANNEALING ON HARDNESS

Since the material under discussion is at times subject to quench-annealing treatments, sections from all three tests were held at 1950° F. for 2 hr. and then water quenched. The results of the hardness determinations are plotted in Fig. 10 together with the results obtained from the other types of heat treatment. It is to be noted that the lowest average hardness in each test weld was obtained in the water-quenched specimens.



(A) Weld deposit. Line of fusion parent metal. 100 X (B) Weld deposit. Line of fusion parent metal. 500 X (C) Parent metal only. 500 X



(D) Weld deposit only. 500 X (E) Weld deposit only. 500 X (F) Weld deposit only. 500 X

Fig. 11 Microstructure of forged and bored Tyye 347 pipe, manually welded using 19% chrome–9% nickel columbium electrode. (A), (B) and (D), as-welded. (E) 2 hr. at 1600° F. and air cooled. (F) water quenched from 1950° F. Etchant, electrolytic 10% chromic acid

MICROSTRUCTURE OF WELDED JOINTS

The microstructure of the 347 base metal and the weld deposits from each test in the various conditions of heat treatment are shown in Figs. 11 to 17, inclusive. The number of photomicrographs appear quite voluminous but are quite in accord with the variety of structures observed with variations in analysis, heat treatment and etching reagents investigated.

The structure of the base metal and manual 19–9 cb weld deposit (test No. 1) after an electrolytic etch in 10% chromic acid, and boiling ferricyanide solution* is shown, respectively, in Figs. 11 and 12. From Figs. 11 (D) and 12 (D) it may be noted that the ferricyanide readily stains the ferrite present whereas the chromic acid has etched only the carbides.†

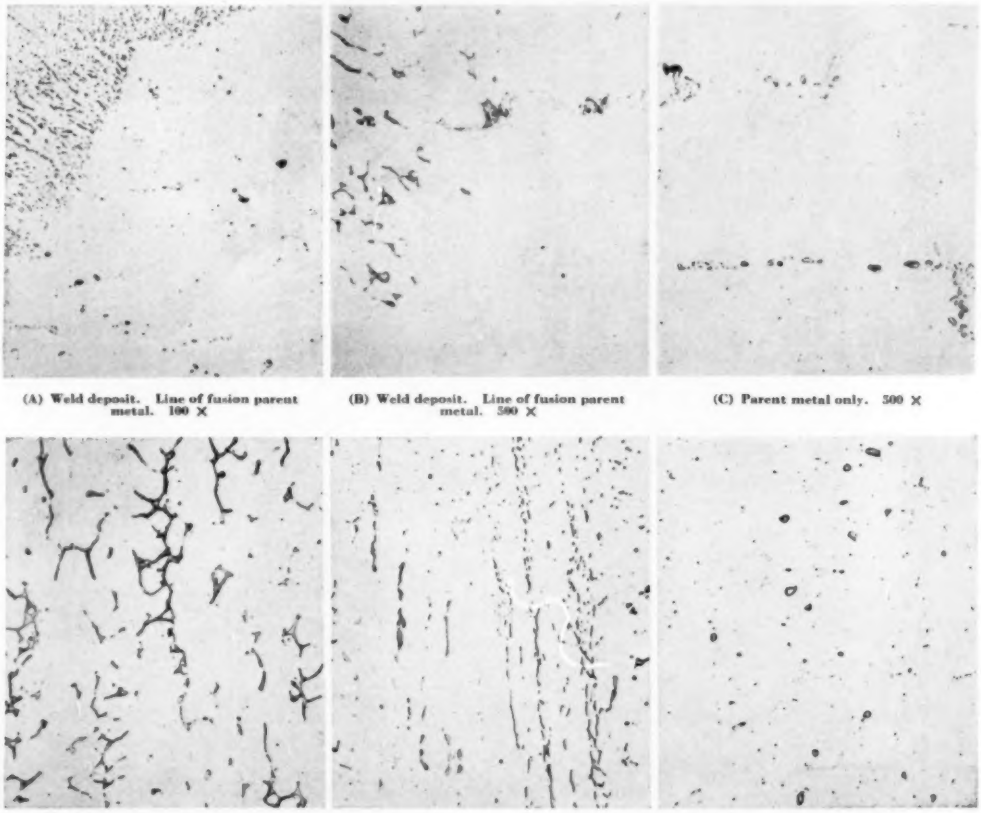
After reheating to 1600° F. for 2 hr. it was found that localized regions of the weld deposit were attacked very rapidly by the chromic acid although the pattern which was attacked was identical to the ferrite pattern shown in Figs. 12 (D) and 12 (E). This structure was believed and subsequently confirmed as sigma phase. Coalescence of the ferrite has occurred to some extent in Fig. 12 (E). As was found by Dulis and Smith,[32] it was difficult to distinguish sigma from ferrite when using ferricyanide when both sigma and ferrite were present in small percentages, owing to inconsistency in the staining of the two phases. Small particles of sigma may, therefore, be present in Fig. 12 (E) but, if so, are not readily distinguishable from the ferrite.

After water quenching from 1950° F., the weld deposit consists of austenite, columbium carbides and scattered pools of ferrite. It is to be noted that there is considerably less ferrite in (F) than in (D) and (E), Fig. 12.

The structures of the submerged-arc 29–9 cb weld deposit are shown in Figs. 13, 14 and 15, the same

* Ferricyanide in this investigation refers to a solution of 1 part potassium ferricyanide, 1 part potassium hydroxide and 2 parts of water. Solution used fresh and boiling.

† Chromic acid will, given sufficient time, etch ferrite also, but where both carbides and ferrite are present, the carbides are preferentially attacked and usually will be completely eaten out before the ferrite structure is fully developed.



(A) Weld deposit. Line of fusion parent metal. 100 ×

(B) Weld deposit. Line of fusion parent metal. 500 ×

(C) Parent metal only. 500 ×

(D) Weld deposit only. 500 ×

(E) Weld deposit only. 500 ×

(F) Weld deposit only. 500 ×

Fig. 12 Microstructure of forged and bored Type 347 pipe, manually welded using 19% chrome–9% nickel columbium electrode. (A), (B) and (D), as-welded. (E) 2 hrs. at 1600° F. and air cooled. (F) water quenched from 1950° F. Etchant, boiling ferricyanide solution

etchants having been used as in Figs. 11 and 12. From (A), (B) and (C), of both Figs. 13 and 14 it is clearly evident that the weld deposit consists of austenite containing a high percentage of ferrite. Although this structure was found to have good ductility, the structures, shown in (D), (E) and (F) of Figs. 13 and 14, have very poor ductility and consist of ferrite (light) and sigma (dark) in a matrix of austenite. The conversion of the unstable ferrite to sigma was responsible for the extreme loss in ductility of the specimens shown in Fig. 9 and the increase in hardness of test No. 2 shown in Fig. 10.

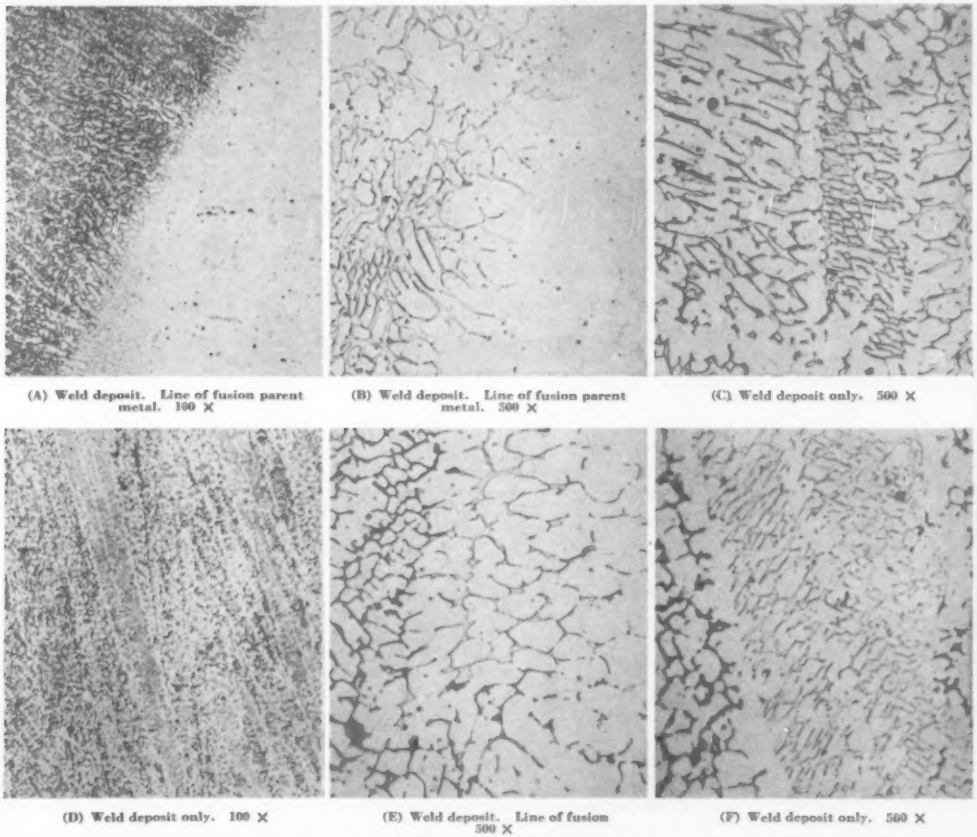
As sigma in this alloy is unstable at temperatures of 1800° F. and higher, water quenching from 1950° F. resulted in a structure of austenite and ferrite as shown in Fig. 15.

The microstructure of the submerged-arc 19–9 cb weld deposit (test No. 3) is shown in Fig. 16. The comments given with respect to Figs. 11 and 12 apply equally well to Fig. 16. The ferrite content of the water-quenched specimens of Fig. 16, however, was found to be negligible.

In addition to (B) and (C) of Figs. 11 and 12, Fig. 17 is presented to indicate the nature of the structure of the base metal directly adjacent to the line of fusion. It may be noted in Fig. 11 (B) that the globular columbium carbides of Fig. 11 (C) are broken up, dissolved and reprecipitated. This structural change is further demonstrated in Fig. 17. From this figure there is evidence to indicate that the columbium carbide was dissolved at an incipient fusion temperature but that time did not permit extensive diffusion. Reprecipitation, however, resulted in structures strikingly like those of a eutectic or peritectic reaction. Whether the structures shown in Fig. 17 were derived from a solid-liquid reaction (peritectic), however, cannot be definitely stated. Close observation of the carbide structures of the deposited weld metal, however, reveal fine structures of similar pattern (see Fig. 38).

SIGMA PHASE—DISCUSSION

In reviewing the literature[26, 27] it was found that pre-



(A) Weld deposit. Line of fusion parent metal. 100 ×

(B) Weld deposit. Line of fusion parent metal. 500 ×

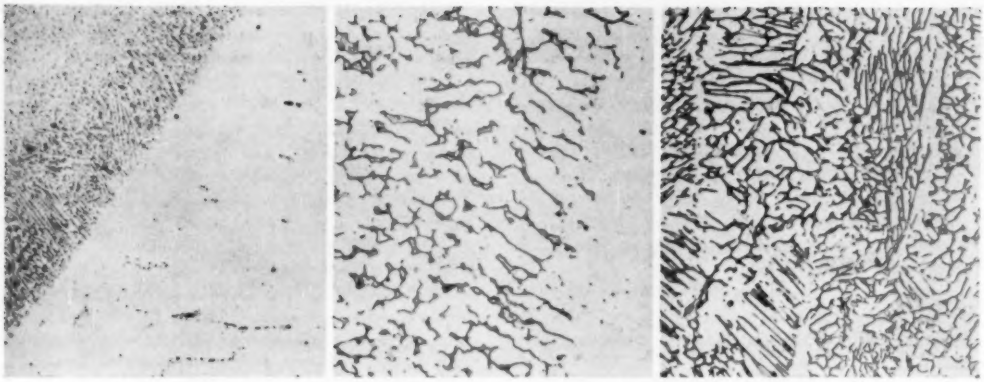
(C) Weld deposit only. 500 ×

(D) Weld deposit only. 100 ×

(E) Weld deposit. Line of fusion 500 ×

(F) Weld deposit only. 500 ×

Fig. 13 Microstructure of forged and bored Type 347 pipe welded by submerged-arc process. Electrode, 29% chrome–9% nickel columbium electrode. (A), (B) and (C), as-welded. (D), (E) and (F), 2 hr. at 1600° F. and air cooled. Etchant, electrolytic 10% chromic acid



(A) Weld deposit. Line of fusion parent metal. 100 ×

(B) Weld deposit. Line of fusion parent metal. 500 ×

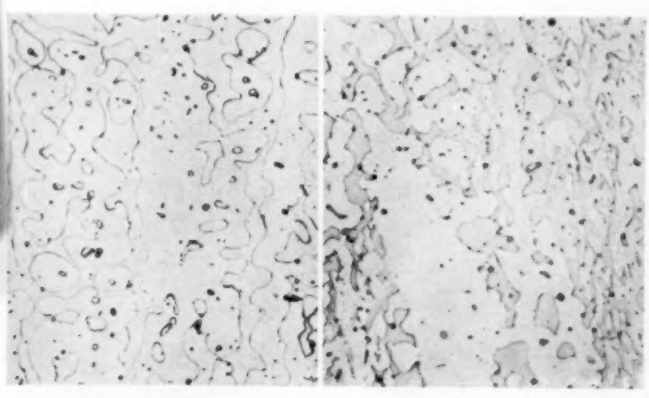
(C) Weld deposit only. 500 ×

(D) Weld deposit only. 100 ×

(E) Weld deposit. Line of fusion parent metal. 500 ×

(F) Weld deposit only. 500 ×

Fig. 14 Microstructure of forged and bored Type 347 pipe, welded by submerged-arc process. Electrode 29% chrome – 9% nickel columbium. (A), (B) and (C), as welded. (D), (E) and (F), 2 hr. at 1600° F. and air cooled. Etchant, boiling ferricyanide solution



(A) Electrolytic 10% Chromic Acid

(B) Boiling Ferricyanide Solution

Fig. 15 29% chromium – 9% nickel-columbium weld deposit after water quenching from 1950° F. 500 ×

vious investigators[5, 7, 8, 16, 25] have determined it expedient to have a small percentage of ferrite present in austenitic weld deposits in order to avoid or eliminate microcracks or fissures in such deposits.

Although the welding literature is not too voluminous, previous publications[5, 8, 25, 27, 35] have shown that this magnetic ferrite phase which is desirable in preventing microfissures can be converted to the brittle nonmagnetic sigma phase due not only to the heat from subsequent layers of deposited weld metal, but also if the weldment as a whole is subjected to subsequent elevated temperatures in the range of 1250–1600° F. On the other hand, the progress of the ferrite to sigma phase change in

numerous of the high-temperature and corrosion-resisting alloys which are normally fabricated by welding, and which are subject to high temperatures either in fabrication and/or in subsequent service, has been followed by observations in the change of magnetic permeability, hardness, strength, ductility, impact values and microstructure by many investigators.[2, 3, 4, 20–23, 31] Others have investigated the nucleation and growth of sigma in the single phase austenitic alloys.[9, 23, 25, 33, 34]

A consideration which should not be overlooked is the fact that sigma has been found to form more rapidly from ferrite than from austenite, and since in many instances weld deposits joining the austenitic alloys consist of both ferrite and austenite, such deposits will sigmatize more rapidly than the base metal being welded.

It appears, therefore, that electrodes should be so balanced as to contain the least ferrite consistent with the deposition of sound crack-free welds. This statement is made since it is the authors' thought that many individuals are more aware of the need for the presence of ferrite to avoid microcracking than they are of the ill effects of the resultant sigma which forms from excessive ferrite in such cases where the weldments are subject to subsequent high temperatures.

For this reason the authors have attempted to present evidence to indicate that the formation of sigma from ferrite in excessive quantity in deposited weld metal, which generally speaking will be detrimental, occurs in a definite pattern with time and temperature and that the resultant mechanical properties are closely tied with the transformation pattern—quantity, size, and distribution of the resultant sigma.

DETERMINATION OF FERRITE CONTENT OF WELD DEPOSITS

The ferrite content of the three test welds were calculated on the basis of chromium and nickel equivalents from the chemical analysis given in Table 1 after the work of A. L. Schaeffler.[15] Tests 1 through 3 were found to contain 5, 20, and 1% ferrite, respectively. It is to be noted that the calculated values are in very

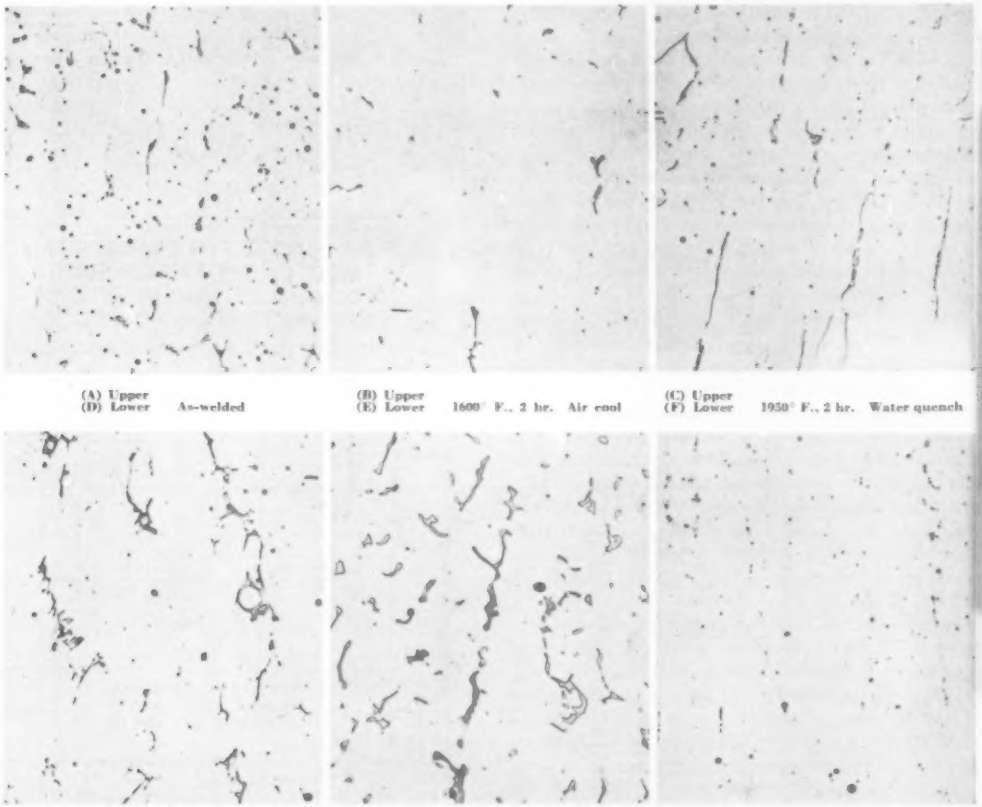
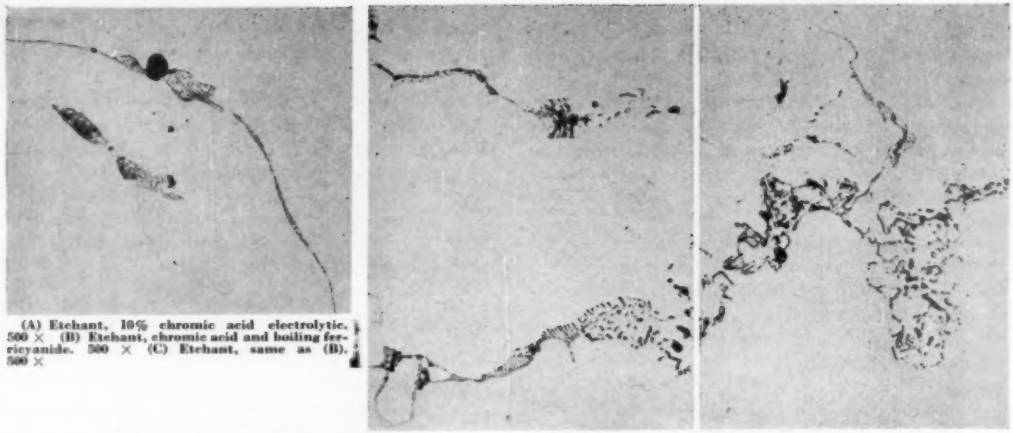


Fig. 16 Microstructure of weld deposit in forged, bored and upset Type 347 pipe, welded by submerged-arc process. Electrode, 19% chromium – 9% nickel-columbium. 500 ×. (A), (B) and (C) etched in 10% chromic acid electrolytically. (D), (E) and (F) etched in boiling ferricyanide solution



(A) Etchant, 10% chromic acid electrolytic. 500 × (B) Etchant, chromic acid and boiling ferricyanide. 500 × (C) Etchant, same as (B). 500 ×

Fig. 17 Type 347 base metal adjacent to line of fusion showing decomposition and reprecipitation of columbium carbide characteristic of structure produced by a peritectic reaction

good agreement with actual measurements of the ferrite content of these welds in the as-welded condition shown plotted in Fig. 18. Although this method serves admirably to determine the phase fields which will be encountered and gives a very close approximation of the percentage of the various phases which will be present, the exact percentage of ferrite cannot be determined by this method; in fact, owing to the general heterogeneous nature of a weld deposit, the ferrite content of the deposits under discussion vary considerably from bead to bead due both to variation in chemistry, and heat treatment resulting from subsequent layers of deposited metal. Early work by Aborn and Bain[1] indicated that for alloys of the 18–8 type, whether wholly austenitic or partially ferritic, there is a temperature range of 1950–2100° F. where maximum austenite will be obtained. Heating these alloys above this temperature will result in the occurrence of (delta) ferrite or an increase in the ferrite in a partially ferritic alloy. This was also quite recently demonstrated by Gilman, Koh, and Zmeskal.[21] It is believed that the above work explains the drop in ferrite content of the deposits in weld tests Nos. 1 and 3 after water quenching from 1950° F., since in the as-deposited condition, the metal was quenched from the solidus (compare (D) with (F) in Figs. 12 and 16).

In order to trace the actual ferrite content from bead to bead and after various heat treatments, the work of Simpkinson and Lavigne was followed.[22] In this work, a Magne-Gage was used which measured the magnetism of the specimen. By means of a rather ingenious method of calibration, the magnetism of the specimen can be converted to percentage of ferrite.

Both of the above methods were discussed and used in calculating ferrite contents in a recent valuable presentation by Schmitz and Scheil.[23] To the authors' knowledge this is the first publication dealing specifically with the effects of sigma on the mechanical properties of columbium stabilized austenitic weldments.

Actual ferrite measurements on the macrosections in which hardness readings were taken and plotted in Fig. 10, are plotted in Fig. 18. It is to be noted that the ferrite in the 29–9 cb deposit dropped from a value in excess of 20% in the as-welded condition to 8.5%

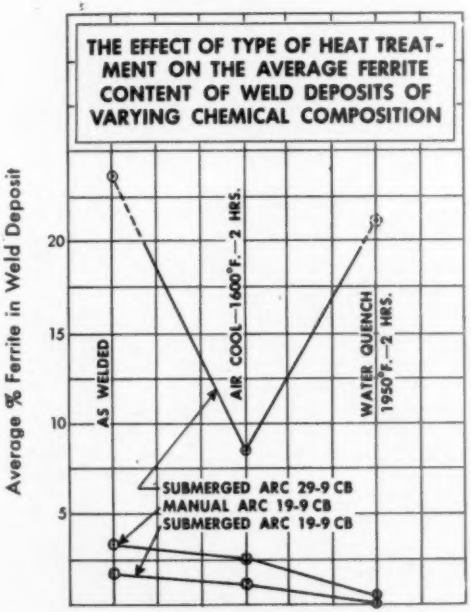

THE EFFECT OF TYPE OF HEAT TREATMENT ON THE AVERAGE FERRITE CONTENT OF WELD DEPOSITS OF VARYING CHEMICAL COMPOSITION
Average % Ferrite in Weld Deposit
20
15
10
5
AS WELDED
AIR COOL—1600°F.—2 HRS.
WATER QUENCH 1950°F.—2 HRS.
SUBMERGED ARC 29-9 CB
MANUAL ARC 19-9 CB
SUBMERGED ARC 19-9 CB
Type of Heat Treatment

Figure 18

after heating to 1600° F. and that a value in excess of 20% was re-established after water quenching from 1950° F. Although this latter value is in excess of 20% it is believed that it is less than the as-welded value and is so indicated in Fig. 18.* The above statement is made in view of the previous discussion of Aborn and Bain's work, and is again verified by the decrease in ferrite obtained in both the 19–9 cb welds (tests Nos. 1 and 3) after water quenching.

TIME-TEMPERATURE RELATION IN THE CONVERSION OF FERRITE TO SIGMA

In establishing the time-temperature relationship in the conversion of ferrite to sigma, numerous slices 1/4-in. thick by 4-in. long were cut from the remains of the as-welded test welds and heated to various temperatures for various periods of time. These slices were then polished through 000 paper and numerous Magne-Gage readings taken on the weld deposits. This was followed by a Rockwell B hardness survey. The specimens were then split in half longitudinally and the upper half containing the major portion of the weld was used for a free bend test to determine weld metal elongation and the lower half containing the root bead was polished for microexamination.

From Fig. 19 it is to be noted that the formation of sigma from ferrite in 29–9 cb occurs quite rapidly, the conversion being almost complete in 25 hr. at 1600° F. This figure also confirms the findings of Schmitz and Scheil relative to the variation in ferrite content from top to bottom of the weld. No explanation is offered for the change in slope of the 25-hr. curve although confirmation of the ferrite in the root pass of this specimen is presented in Fig. 23.

The effect of time at 1600° F. on the conversion of ferrite to sigma in all three test welds is plotted in Fig. 20 and the resultant effects on the hardness and free bend elongation values are plotted in Figs. 21 and 22. It is to be noted from Fig. 20 that water quenching the 29–9 cb analysis from 1950° F. prior to heating at 1600° F. results in some degree of stabilization of the ferrite. This may be due to the solution, and more favorable partitioning, of the ferrite-forming elements in the austenite during the 1950° F treatment. It may be likewise due to the increase in size of ferrite pools and

* All values in excess of 20% ferrite are shown dotted as the calibration curve of Simpkinson and Lavigne was used which extended only to this value.

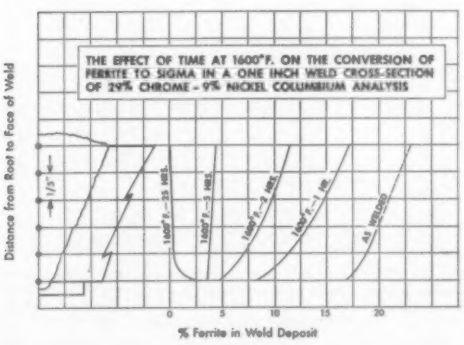

THE EFFECT OF TIME AT 1600°F. ON THE CONVERSION OF FERRITE TO SIGMA IN A ONE INCH WELD CROSS-SECTION OF 29% CHROME - 9% NICKEL COLUMBIUM ANALYSIS
Distance from Root to Face of Weld
1/2"
1600°F.—25 HRS.
1600°F.—5 HRS.
1600°F.—1 HR.
AS WELDED
0
5
10
15
20
% Ferrite in Weld Deposit

Figure 19

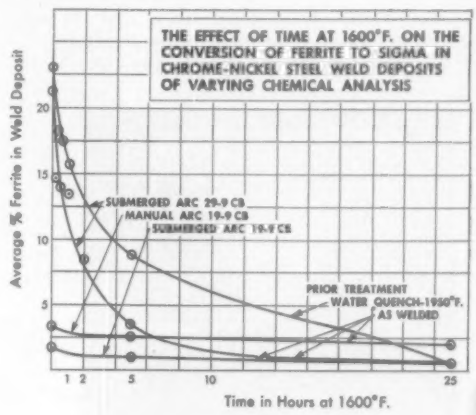


Figure 20

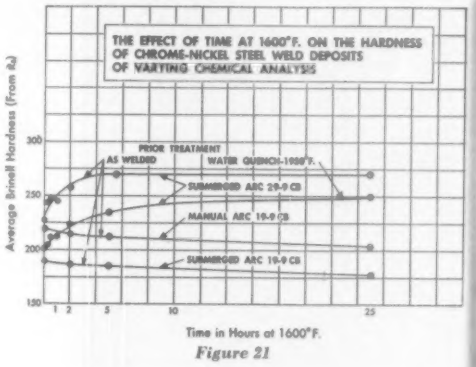


Figure 21

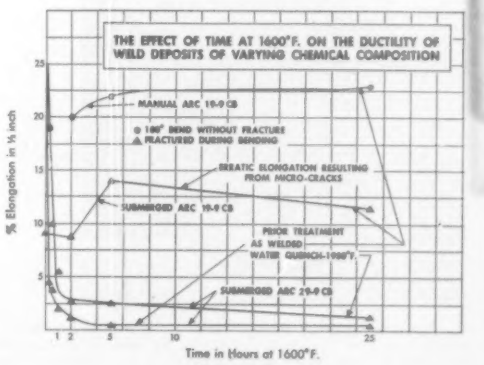


Figure 22

therefore decrease in ferrite-austenite interface which would decrease the rate of sigma formation if the initial transformation occurs at the austenite-ferrite interface as microscopic evidence seems to indicate. This is, in general, confirmation of the work of Emmanuel on "Sigma Phase in the 25–20 Austenitic Alloy".[34] He has likewise indicated that sigma phase is generally nucleated at grain boundaries and that it is not surprising, therefore, that a decrease in grain boundary area would diminish the precipitation of sigma.

The fact that almost complete conversion of over 20% ferrite to sigma occurred in the 29–9 cb composition in 25 hr. and that a drop of only 1½% in the ferrite content (3.5 to 2.0) occurred in the manually deposited 19–9 cb in the same period of time is believed to be due to the amount and concentration of the ferrite-forming elements present in the ferrite. Numerous investigators have shown that chromium, molybdenum, tung-

Fig. 23 The effect of time at 1600° F. on the conversion of ferrite (top) to Sigma (bottom) in an austenitic matrix of a 29% Cr – 9% Ni-cb weld deposit. 1 ×. Etchant 10% chromic acid electrolytically

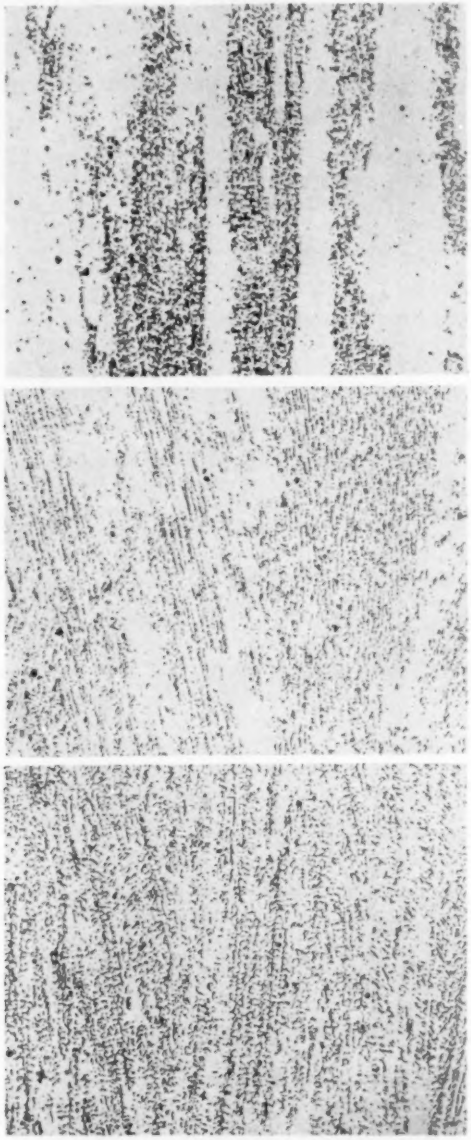
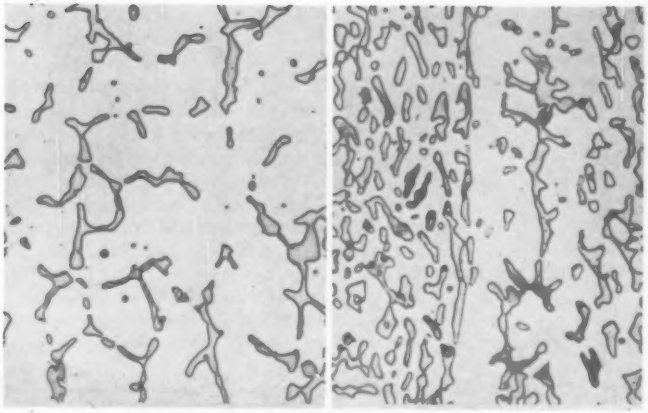


Fig. 24 The effect of time at 1600° F. on the formation of sigma phase (dark constituent) from ferrite in an austenitic matrix in a 29% Cr – 9% Ni-cb weld deposit. Etchant, 10% NaCN electrolytically. 100 ×

(Top) 1 hr., 1600° F. (Center) 5 hr., 1600° F. (Bottom) 25 hr., 1600° F.



(A) Electrolytic 10% NaCN (B) Boiling ferricyanide

Fig. 25 Essentially complete conversion of ferrite to sigma in a 29% Cr – 9% Ni-cb weld deposit after 25 hr. at 1600° F. 1000 ×

sten, titanium, columbium, silicon and aluminum, all ferrite-forming elements, are likewise potent sigma-forming elements.[3, 4, 9, 14, 31, 34] In this respect the 29–9 cb analysis, in addition to having a large excess of chromium, contains silicon slightly in excess of 1% and columbium in excess of that required to tie up all carbon on the assumption that the carbide is present as CbC. Some differences in opinion appear to exist as to the effect of columbium in promoting sigma formation. Binder[32] states, "Columbium is classified as a ferrite-forming element, but in 18–8 steel it is relatively weak in this respect. Instead of producing ferrite, it combines with carbon to form the carbides CbC and M_6C and the columbide Fe_2Cb_2. The latter two phases, however, appear only in steels containing more than 1% columbium. The propensity of columbium to form carbides and Fe_2Cb_2 is the probable reason for its relatively weak ferrite- and weak sigma-promoting characteristics." In contrast to this Emmanuel[34] states, "In addition to their ferrite-forming tendencies, titanium and columbium exert a further accelerating influence on sigma formation by stabilizing the carbon, thereby permitting maintenance of a higher effective chromium content in the matrix."

The 19–9 cb welds, on the other hand contained only a slight excess of ferrite as evidenced in Fig. 20 and it is suspected that these are lean in the ferrite forming elements. It does not seem surprising, therefore, that the rate of the ferrite to sigma reaction would be slower in these deposits than in that of the 29–9 cb analysis.

The effect of the ferrite stabilization from the 1950° F. prior quench is reflected in both the hardness and elongation values of the 29–9 cb analysis given in Figs. 21 and 22. The benefits in elongation values derived from this treatment in the specific case in question however, make it of little more than academic value.

Paralleling the ferrite to sigma phase change with increase in time at 1600° F., as plotted in Fig. 20, are Figs. 23 and 24 which macroscopically and microscopically depict these changes. The macrographs were made by polishing to 000 paper and etching electrolytically with 10% chromic acid. The specimens were then lightly polished with 000 paper containing graph-

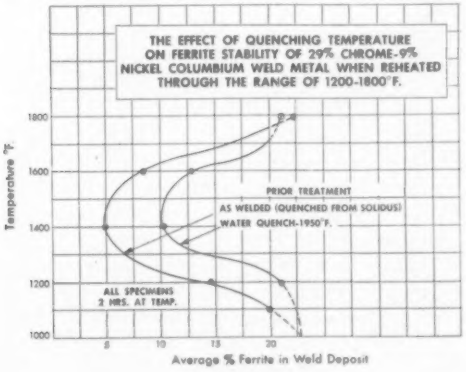


Figure 26

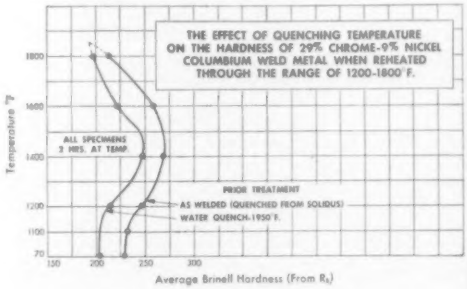


Figure 27

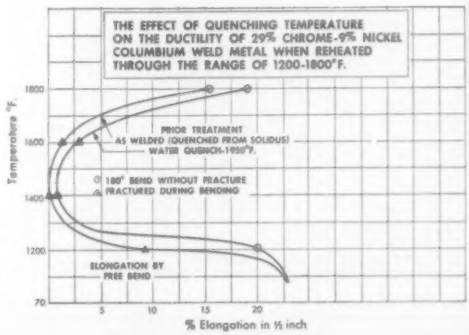


Figure 28

ite. By so doing, the etch was removed from the ferrite (light constituent) which was left in relief by the etching. The lighting used to photograph the specimens was therefore reflected from the ferritic dendrites which gave contrast between the ferrite and the sigma phase (dark constituent). The phase change was also followed microscopically as shown in Fig. 24 by etching the specimens electrolytically in 10% sodium cyanide. The sigma is readily etched by this procedure leaving the ferrite areas unetched. The structural detail of the sigma phase of Fig. 24 is shown in Fig. 25 (A) at 1000 diameters magnification. The same specimen after repolishing and etching in boiling ferricyanide solution is shown in Fig. 25 (B). The inconsistency in the colors of staining of sigma phase pointed out by Dulis and Smith[22] are likewise to be noted from this figure.

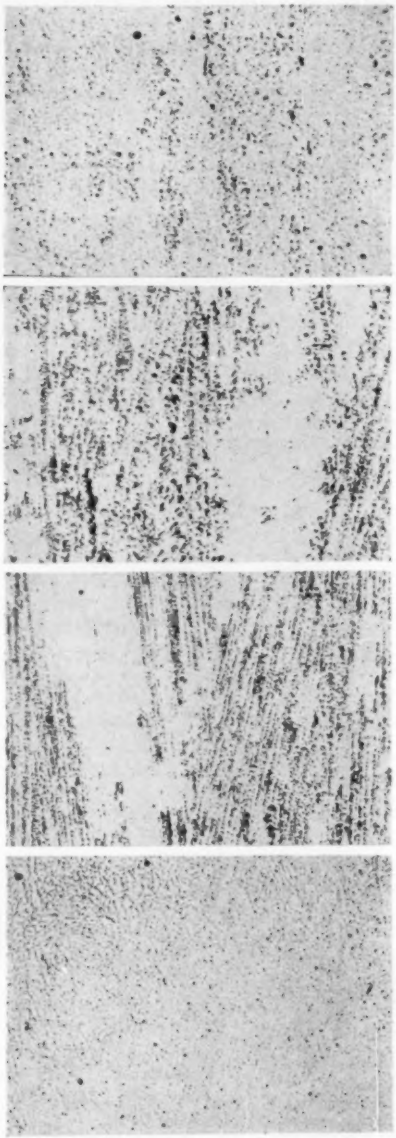


Fig. 29 The effect of temperature on the formation of sigma phase (dark constituent) from ferrite in an austenitic matrix in a 29% Cr–9% Ni-cb weld deposit. Etchant, 10% NaCN electrolytically. 100 ×

Whereas Figs. 19 to 24, inclusive, portrayed the effect of time at constant temperature on the conversion of ferrite to sigma, Figs. 26 to 29, inclusive, depict the effect of temperature with constant time. From Fig. 26 it is to be noted that the rate of formation of sigma is more rapid at 1400 than at 1600° F., that ferrite is the stable phase at 1800° F. and that water quenching from 1950° F. produces a stabilizing effect on the ferrite.

The results of both hardness and elongation plotted in Figs. 27 and 28 appear to be consistent with both Fig. 26 and each other. Greatest hardness and lowest elongation values resulted from heating to 1400° F. Good ductility was obtained as noted by other investigators,[2, 3] after heating to 1800° F. at which temperature ferrite is the stable phase. The stabilizing effect on the ferrite from the 1950° F. water quench was reflected by both lower hardness and slightly improved elongation values. Photomicrographs of the specimens from which the data plotted in Fig. 26 was obtained, are shown in Fig. 29. From this figure it is to be observed that sufficient diffusion has occurred in the 1200° F. specimen to form minute sigma particles (dark) although ferrite in the austenite is predominant. At 1400 and 1600° F., the sigma phase is predominant although large unetched patches of ferrite are present. At 1800° F., however, the sigma phase is not stable and the structure consists of ferrite in an austenite matrix.

Since from Figs. 26 and 29, there is evidence that nucleation and growth of sigma from ferrite occurred in the as-welded specimen heated to 1200° F., the question was raised as to whether sigma was the stable phase at 1100° F.

It was most surprising to the authors to find from the data plotted in Fig. 30 that the ferrite to sigma

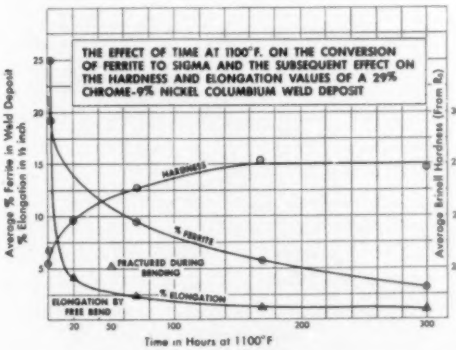


Figure 30

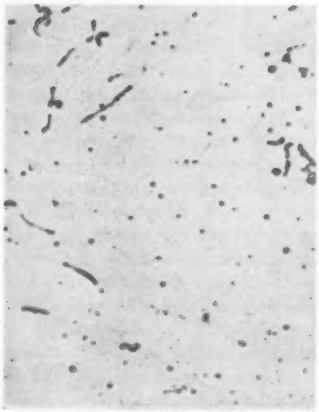


Fig. 31 Initial stage in the transformation of ferrite to sigma in a 29% Cr – 9% Ni-cb weld deposit after 1200° F. for 2 hr. Etchant, 10% NaCN electrolytically. 1000 ×

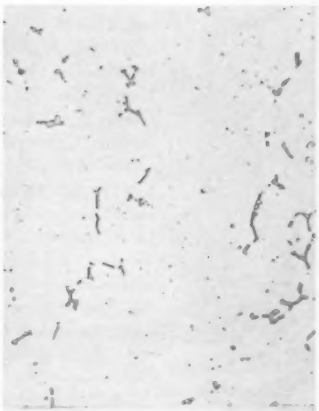


Fig. 32 Sigma phase in manually deposited 19% Cr – 9% Ni-cb weld metal after 2 hr. at 1600° F. Etchant, 10% NaCN electrolytically. 500 ×

phase change was nearly complete in as few as 300 hr. at temperature, that ductility as measured by elongation in free bending was less than 5% after as short a period as 20 hr. and that, microscopically, sigma was resolvable in as short a period as 2 hr. at 1100° F. Having determined the presence of grain boundary sigma at 1100° F., the as-welded 29–9 cb specimens were re-examined and likewise found to show traces of sigma. It is to be pointed out that sigma in the as-welded specimen and in the specimens reheated to 1100 and 1200° F. for 2 hr. would have undoubtedly been undetected microscopically had it not been that it was possible to progressively follow this phase change microscopically over a wide range of time and temperature as well as following this change by other means. A further review of the specimens from the two 19–9 cb tests heated to 1600° F. for 2 hr., revealed microscopically the presence of sigma in both, although the quantity in each case was small in keeping with the ferrite originally found to be present.

The initial stages of grain boundary sigma precipitation in the 29–9 cb analysis after 2 hr. at 1200° F. is shown in Fig. 31 at 1000 diameters magnification. The presence of sigma phase in the manually deposited 19–9 cb weld after heating to 1600° F. for 2 hr. is confirmed in Fig. 32.

In view of the information established at 1100° F. and plotted in Fig. 30, which temperature is only 50° above the actual operating temperature of certain existing central stations, and at/or below contemplated steam temperatures, the presence of excessive ferrite in weld deposits should be of more than casual concern.

MICROFISSURES IN SUBMERGED ARC 19–9 CB WELD DEPOSITS

Numerous specimens from the 19–9 cb submerged arc weld (test No. 3) were examined microscopically not only in the as-welded condition but also after air cooling from 1600° F., and after water quenching from 1950° F.

The chemical and metallographic data presented

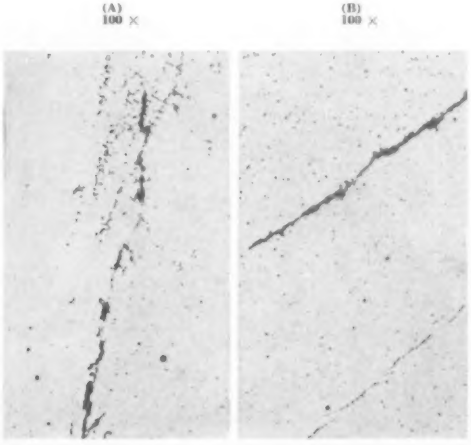


Fig. 33 Microcracks in austenitic weld deposit. Note that crack does not extend through the small amount of ferrite in (A). Etchant, boiling ferricyanide solution

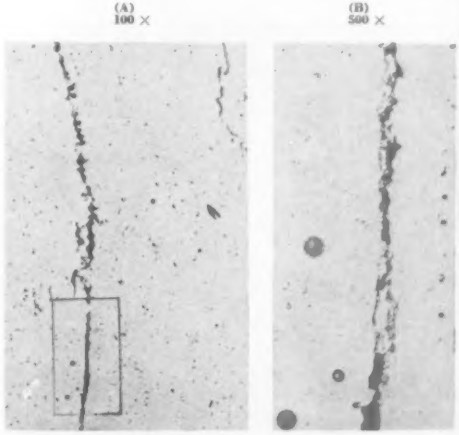
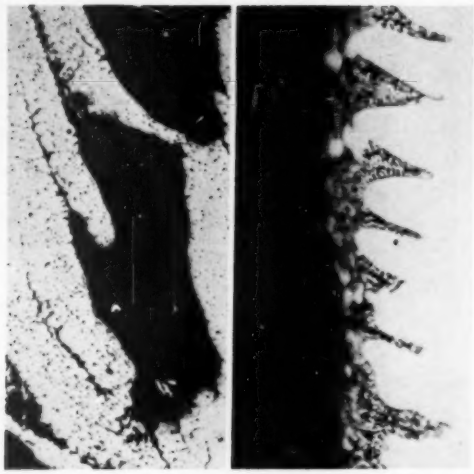


Fig. 34 Microcrack (A) in austenitic weld metal containing less than 1% ferrite and detail (B) of enclosed area of crack (A). Etchant, electrolytic chromic acid followed by boiling ferricyanide solution



(A) 100 × (B) 1000 ×

Fig. 35 Major crack in a submerged-arc 19% chromium – 9% nickel columbium weld deposit. Etchant, 10% chromic acid electrolytically. (A) Austenitic structure surrounding major crack and its numerous extensions. (B) detail of cracked interdendritic structure

herein are in general agreement with the experience of other workers who have investigated microcracking in the welding of higher chrome-nickel alloys.

Campbell and Thomas[7] have shown that to avoid microcracks in 25–20 weld deposits, carbon should be held in the range of 0.10–0.20% and silicon in the range of 0.40–0.60%. Within different limits, however, Rozet, Campbell and Thomas[17] showed a similar carbon-silicon trend to avoid microcracking in 15–35 alloy weld deposits. The work of Carpenter and Jessen[12] in effect confirmed the work of Campbell and Thomas, indicating that silicon above 0.50% in conjunction with carbon below 0.12% would result in defective welds in 25–20. They further stated, "The harmful effect of high silicon values in 25% chrome–20% nickel weld deposits is not due to the metallic silicon in solution in the austenite but rather to the formation of silicate films surrounding the austenite grains." Very recently Carpenter, and co-workers[28] presented an excellent paper, which in part covered the factors responsible for microcracking in fully austenitic weld deposits of the 19–9 composition. This work in effect confirmed their previous findings[12] on the 25–20 alloy. Low carbon (below 0.10%) resulted in microcracks even with low silicon values. Increasing the carbon to 0.15–0.17% eliminated the microfissures provided the silicon content did not exceed about 0.50%, although fissures were again produced with a further increase in silicon. This relationship was found to exist in 19–9 as well as 19–9 cb and it was therefore concluded that columbium did not substantially effect the soundness of such welds. Carpenter and his co-workers also determined that columbium in the weld deposit, whether present from the electrode or the base metal, resulted in crater cracking. Although the microfissures found from low carbon or high silicon or both were attributed to a silicate slag film, a theory which they previously published, the crater cracks found were stated to be intergranular and the result of an intergranular microstructural constituent which did not appear to be of a slag type. Kihlgren and Lacy[6] indicated the need of a high columbium to silicon ratio to prevent microfissures in 15–35 alloy weld deposits. Linnert[16] found extensive cracking in predominantly austenitic weld deposits in the welding of turbo-supercharger wheels which he attributed to low melting interdendritic segregates.

A review of Table 1 indicates that the carbon and silicon contents of 0.066 and 1.00%, respectively, are well outside the limits for sound welds in the 19–9 or 19–9 cb compositions as well as those of the 25–20 and

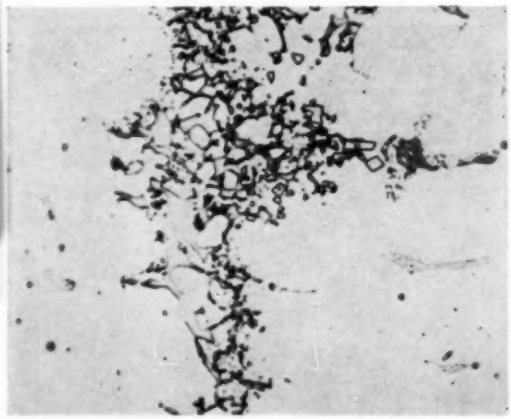


Fig. 36

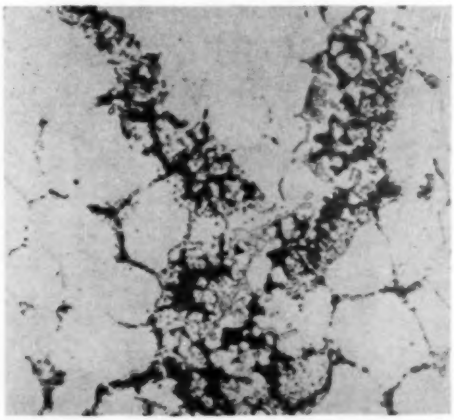


Fig. 37

(Fig. 36) Ferricyanide etch. 1000 ×. (Fig. 37) Electrolytic chromic etch. 1000 ×. Structures resulting from segregation and paralleling microcracks

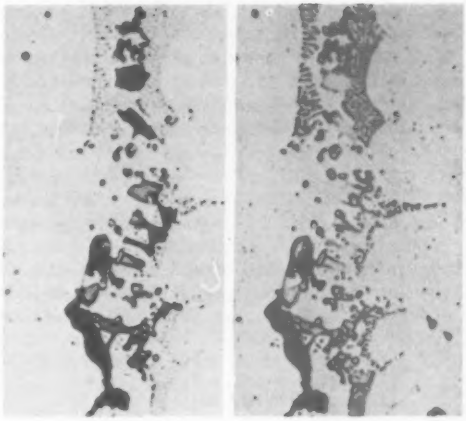
15–35 alloys. Whereas the silicon content is even higher (1.18%) in the 29–9 cb analysis, it has been previously pointed out by both Campbell and Thomas, and Carpenter, Jessen and co-workers, that the addition of ferrite-stabilizing elements to the weld deposit will prevent microfissures despite high silicon.[7, 12, 28] This has been previously verified by the authors.

Although Carpenter, Jessen and co-workers[12, 28] presented considerable evidence to substantiate their silicate slag film theory in the manual welding of 25–20 and 19–9, the authors were unable to locate such films in and adjacent to the cracks encountered in the submerged arc 19–9 cb deposit. The deposit contained large amounts of silicates, however, but they were of the globular glassy type. The type of inclusions were confirmed by examination under polarized light.

The general nature of, and microstructural detail adjacent to, the cracks as shown in the following photomicrographs is in general confirmation of the work of Linnert[16] and that of Carpenter, Jessen and co-workers[28] relative to their findings in crater cracks.

Indicating that this weld is predominantly austenitic and that the cracks are interdendritic in nature, Figs. 33 and 34 are presented. The microstructure of one of the large cracks shown in Fig. 7 is presented in Fig. 35. In the detail (B) of this crack, an austenitic dendrite (right) is shown together with the lower melting interdendritic "pine-tree" segregate (center). This eutectic-type structure is not too unlike that shown in Figs. 17 and 38 and is postulated to be composed of austenite and columbium carbide.

Further evidence of segregation and complexity of microstructure is presented in Figs. 36 and 37. In addition to ferrite and columbium carbide being present in Fig. 36, a clear etching angular type structure may be observed. Since boiling ferricyanide stains both ferrite and sigma and rapidly attacks columbium carbide, it would appear that the angular type structure is still another phase.



(A) Boiling ferricyanide (B) Boiling ferricyanide plus chromic acid

Fig. 40 Structure paralleling Microcrack after water quenching from 1950° F. 1000 ×

The heavily etched network in Fig. 37 was previously etched electrolytically in sodium cyanide which revealed this structure to be of sigma composition. Further etching electrolytically in chromic acid rapidly attacked the sigma network in addition to revealing both eutectic and globular carbides. The columbium carbide-austenite eutectic found in columbium bearing weld deposits is shown in Fig. 38. This structure closely resembles those of Figs. 17 and 35 (B). The authors are of the opinion that this structure lacks high temperature ductility and the material containing this structure in substantial amounts would require extreme care in original ingot reduction.

Two views of the same area of the specimen heated at 1600° F. for 25 hr. are shown in Fig. 39 after etching electrolytically first in sodium cyanide followed by chromic acid. The clear etching sigma structure following the microcrack may be seen to be heavily attacked by the chromic acid which further verifies the presence

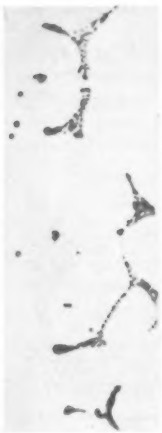
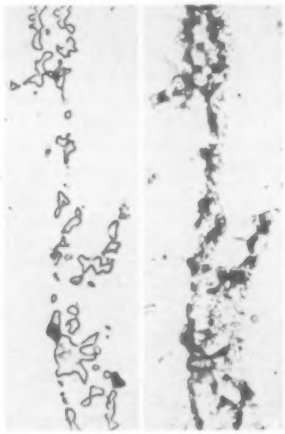


Fig. 38. Columbium carbide-austenite eutectic. 1000 ×. Etchant, electrolytic chromic acid



Electrolytic sodium cyanide | Electrolytic sodium cyanide plus chromic acid

Fig. 39 Sigma phase paralleling microcrack after 25 hr. at 1600° F. 1000 ×

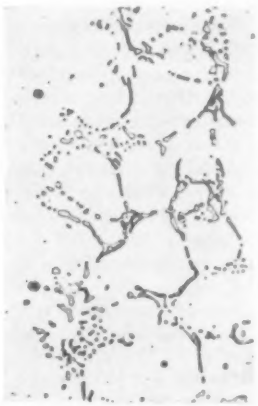


Fig. 41 Structure extending beyond end of microcrack after water quenching from 1950° F. Etchant, electrolytic chromic acid. 1000 ×

of sigma. Additional carbides were revealed by the chromic etch.

Two views of the same area of the specimen water quenched from 1950° F. are shown in Fig. 40 after etching first in boiling ferricyanide followed by chromic acid. The structure following the microcrack in (A) appears to be eutectic carbide and ferrite. Although the ferrite appears to be somewhat angular and dark, this structure was essentially removed by the chromic etch as shown in (B). This verified previous experience on similar specimens using this double etch technique. An extension of the structure beyond one of the cracks after electrolytically etching in chromic acid revealed a network of globular carbides with some ferrite areas present.

CONCLUSIONS

1. A manually deposited weld joining heavy wall Type 347 austenitic pipe has been shown to have adequate strength and ductility in the as-welded condition when the deposit contains 3 to 5% ferrite and the silicon is in the range of 0.50 to 0.60%.

2. A submerged-arc weld joining heavy wall Type 347 austenitic pipe has been shown to have adequate strength and ductility in the as-welded condition when made using a 29–9 cb electrode. The ferrite content of a weld deposit of this type was found to be approximately 20–25%.

3. High silicon (1.18%) usually associated with hot-cracks in single-phase austenitic weld deposits is not a deterrent in this respect when the deposit contains a substantial quantity of ferrite.

4. A submerged-arc weld made using a conventional 19–9 cb electrode was found to be unsatisfactory from the standpoint of microcracks or fissures. The deposit averaged only 2% ferrite and, being heterogeneous, the cracks were found in the ferrite-depleted areas. It is believed that a 50% reduction of the silicon and a 10% increase in the chromium in the deposit would have been effective in overcoming this difficulty.

5. The ferrite- and austenite-forming elements in electrodes used in joining Type 347 austenitic steel piping which are subject to high temperatures should be so balanced as to contain the least ferrite in the deposit consistent with the deposition of sound crack-free welds.

6. In austenitic weld deposits containing ferrite, the ferrite is quite readily converted to sigma if a post weld heat treatment in the range of 1250–1600° F. is used, or if the weldment is subject to long-time service in the range of 1050–1200° F.

7. In austenitic weld deposits containing as much as 20–25% ferrite, the ferrite to sigma phase change was found after 2 hr. of heating to be 39% complete at 1200° F., 78% complete at 1400° F. and 63% complete at 1600° F.

8. Most surprising, it was found that in austenitic deposits high in ferrite, the ferrite to sigma phase change was 85% complete in as few as 300 hr. at 1100° F.

9. As the brittle nonmagnetic sigma phase forms, weld metal hardness increases, and the ductility is drastically reduced.

10. Austenitic weld deposits low in ferrite and therefore having a low sigma potential, remain ductile after heating in the range of 1100 to 1600° F. since the total quantity of sigma present is insufficient to adversely affect the ductile austenitic matrix.

11. Ferrite, not sigma, is the stable phase at temperatures of 1800° F. and higher.

12. The ferrite to sigma phase change takes place more slowly in the 1100–1600° F. range if the weld deposit is previously given a 1950° F. water quench. Such a treatment may be said, therefore, to have a stabilizing influence on the ferrite.

13. Austenitic weld deposits containing a high silicon content are believed to require a higher percentage of ferrite in the deposit than those of normal silicon content to avoid microcracks or fissures.

14. Microcracks which were prevalent in an austenitic weld deposit of the 19–9 cb type containing high silicon and low ferrite, when made by the submerged-arc process, were found to be interdendritic in nature, and the result of hot-short low-melting complex segregates.

15. Although no residual stress measurements were made on the welded joints covered in this investigation, the authors are of the opinion that a properly welded joint in Type 347 material has adequate strength and ductility in the as-welded condition and that no specific advantages are to be gained by a postweld treatment of 1250–1600° F.

ACKNOWLEDGMENTS

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38. Carpenter, O. R., Jessen, N. C., Oberg, J. L., and Wylie, R. D., "Some Considerations in the Joining of Dissimilar Metals for High-Temperature, High-Pressure Service," presented at the Fifty-third Annual Meeting of the American Society for Testing Materials, June 26–30, 1950.

Discussion by R. H. Aborn

This paper is a valuable addition to our knowledge of the properties of an important grade of stainless-steel weld metal. We hope that the authors will extend their investigation to include the base metal which poses some rather serious problems when thick sections of this grade of stainless steel are welded under restraint.

The effect of the 1950° F. treatment in reducing the delta ferrite content of the 19–9 Cb weld metal is remarkable, as such a treatment generally has a negligible effect in reducing the delta ferrite customarily found in 18–8 ingots. This marked difference in behavior suggests there is much less difference in composition between the ferrite and austenite of the weld metal as compared to the difference in composition between the same two phases in an ingot, presumably due to the much faster freezing of the steel in welding.

The marked change in slope of the ferrite curves in Fig. 19, with increase in holding time at 1600° F., suggests a distinct difference in behavior of the root and face zones of the weld. The root zone contains a higher proportion of base metal, which means that it will be lower in chromium and silicon than in the face zone; also, it is quite possible that the shape and distribution of the ferrite particles are distinctly different in the two zones. We suggest that one or more of these factors may be responsible for this unusual change in the rate of sigma formation with time and location in the weld.

It is significant that the silicon level in both of the submerged-arc weld metals is much higher than in the manual weld metal; thus the higher rate of formation of sigma in the 29–9 weld metal would appear to be due to the higher chromium level producing much more delta ferrite, which in turn provides a much greater surface area on which the sigma reaction can proceed. It may be noted also that the ferrite in the as-welded 29–9 weld metal tends to be very elongated, whereas in the same weld metal after the 1950° F. treatment it is considerably more rounded, thereby having less surface area. We suggest that this characteristic of the 1950° F. treatment together with its homogenizing tendency may be important factors in retarding the rate of sigma formation.

There is some question whether the presence of carbide and its effects were kept in mind sufficiently in interpreting the constituents in some of the micrographs. For example, in Fig. 31 it is well known that sodium cyanide etches carbide as well as sigma, so the evidence for the formation of sigma in that micrograph is uncertain because of the probability that a considerable part of the black etching particles may be carbide.

The use of as many welding passes with the submerged-arc process as with the manual shielded-arc process seems so unusual that the authors might comment upon it.

Finally, one question comes to mind. Is Type 347 (18–8–Cb) steel necessary for this application? The scarcity of columbium indicates the desirability of facing this question squarely, with serious consideration of simpler substitutes in connection with a modified design if required.

R. H. Aborn, Asst. Director of Research, U. S. Steel Co. Research Laboratory, Kearny, N. J.

Discussion by R. David Thomas, Jr.

The authors have presented data in this paper which I am certain will be looked upon as a valuable reference in the future by anyone who undertakes to study Type 347 welds.

My first comment is intended to supplement their

R. David Thomas, Jr., Vice-President and Director of Research and Engineering, Arcos Corp., Philadelphia, Pa.

discussion of Fig. 19, by offering an explanation for the reversal of slope observed as a result of long-time heat treatments. Throughout the paper the authors demonstrate the occurrence of sigma formed from the ferrite constituent in this type of weld during heat treatment. The weld containing less than 5% ferrite shows no embrittlement, whereas the one containing 20% becomes very brittle. Is it not reasonable to suppose that somewhere between 5 and 20% the transformation to the brittle sigma phase is only partial? This appears to be demonstrated in Fig. 19 where, because of dilution, the root passes have less ferrite than the top passes and where, after 25 hr. at 1600° F., those areas containing less than 20% ferrite are not completely transformed and show some of the magnetic ferrite phase remaining.

My second comment deals with the field of application of 29–9 Cb wire for submerged-arc welding. In view of the very obvious embrittlement demonstrated by the authors' heat-treated welds, one is prone to conclude that this type of wire is not suitable for welding Type 347. I feel certain the authors will agree, based on their own results, that the use of this type of wire for submerged-arc welding is perfectly feasible for structures which are to remain in the as-welded condition and which are not to be used in elevated temperature service. A more debatable point might be its possible application, even in heat-treated structures or in structures subjected to elevated temperatures, wherein the joint design is somewhat different. Submerged-arc welds prepared in our laboratory, using the same heat of wire employed by Mr. Emerson and his associate, but deposited under conditions involving considerably more dilution, gave a weld metal having the following chemistry:

C	0.052
Mn	1.69
Si	0.94
S	0.013
P	0.031
Cr	20.79
Ni	10.78
Cb	0.76
Ferrite (as-welded), %	10

Although the welds were not tested for ductility after postheat treatments, the corrosion data on specimens sensitized at 1200° F. gave no evidence of sigma. The above composition is not unlike that frequently obtained from manual-arc welds. One may conclude, therefore, that the 29–9 Cb type wire may prove extremely useful in submerged-melt welding of Type 347, providing the weld composition in its finally deposited state is reasonably comparable to the usual standards for Type 347 hand-arc welds.

The authors' contributions to the subject of microfissuring are stimulating even though I cannot fully agree with many of their contentions. It is extremely difficult to base conclusions upon another person's photomicrographs even though they are of the excellent quality found in this paper. I seriously question the existence of sigma phase which the authors consider is identified in Fig. 39. I question whether sigma phase is in any way related to microfissuring. Furthermore, in our experience, the presence of the columbium carbide-austenite eutectic, shown in Figs. 38 and 40, has been found to reduce the tendency to microfissures rather than the reverse as indicated by the authors. In casting doubts on the authors' explanations, I admit my inability to offer constructive theories to take their place. For the present my contribution to this subject will have to be limited to sounding a note of caution with regard to accepting Mr. Emerson's explanations. Nevertheless, the excellent discussion and illustrations are worthy of a very careful study.

It is gratifying to note the interest which has apparently been generated in the properties of Type 347 weld metal. Every year we find more investigations on this subject, each contributing a part to our knowledge of its properties and simultaneously to the understanding of stainless weld metal generally. It is only through the combined efforts of first-class investigators such as these that the fundamental concepts of the stainless weld metal will be fully understood.

Discussion by N. C. Jessen

We would like to express our appreciation to Mr. Emerson for having afforded us the opportunity to review this paper prior to its presentation. The authors are to be complimented on having added another page to our knowledge of the welding of the columbium-bearing stainless steels.

The application of submerged-arc welding to the welding of stainless steels in itself is not new, however, we are not aware of any application of this process to stainless equipment for high-temperature high-pressure service. In view of the fact that the quality of an 18 Cr–8 Ni type of weld deposit depends to such a large extent on its microstructure, which in turn is a function of the degree of base metal dilution, it would appear that considerable research work has to be done before this process of welding may be safely applied to high-temperature high-pressure equipment.

The addition of columbium to an 18 Cr–8 Ni type of weld metal produces some interesting changes in the properties of such weld metals. Normal columbium additions, for example, result in reduction of room-temperature ductility of from about 50 to 35% elongation in 2 in. Moreover, the addition of columbium also results in the appearance of a new phase in the microstructure which the present authors identify as a columbium-carbide austenite eutectic. Our own work indicates that in ferritic as well as austenitic alloys this phase disappears as either carbon or columbium

N. C. Jessen, Works Control Laboratory, The Babcock and Wilcox Co., Barberton, Ohio.

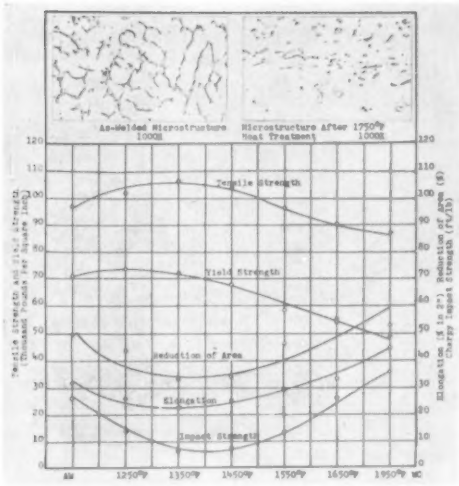
As-Welded Microstructure 1000X
Microstructure After 1750°F Heat Treatment 1000X
Tensile Strength
Yield Strength
Reduction of Area
Elongation
Impact Strength
Tensile Strength and Yield Strength (Thousand Pounds per Square Inch)
Elongation in 2"; Reduction of Area (%)
Charpy Impact Strength (Ft/Lb)
As 1250°F 1350°F 1450°F 1550°F 1650°F 1950°F WQ

Fig. 1 Physical properties of 19–9 Cb weld metal after various stress-relieving heat treatments

approach zero. We have also noted that the presence of this constituent in substantial quantities (Cb 1% or over), invariably results in considerable crater cracking of arc-weld deposits. Columbium additions to the 18 Cr–8 Ni type austenitic stainless steels are normally made in a ratio of 10 Cb to 1 C, based on room-temperature corrosion resistance requirements. It may be of general interest that columbium additions of as little as 5:1 may effectively strengthen the 18 Cr–8 Ni type alloys in high-temperature stress applications. Figure 1 shows a comparison of the stress-rupture properties of 18 Cr–8 Ni alloys with various columbium additions. It may be possible to reduce the columbium content in stabilized 18 Cr–8 Ni materials and weld metals for high-temperature high-pressure service with resultant conservation of a critical material and a reduction in the crater cracking tendencies of the deposited weld metal. It should be recognized that these are relatively short time-test data and subject to confirmation. Stress rupture data obtained for such short time periods usually result in considerable scatter of values.

The most interesting portion of the present paper is in my opinion the author's discussion of the role of ferrite in the microstructure. The preferred composition of 3 to 5% ferrite appears to be somewhat on the low side in that dilution, particularly in the root passes, may well result in cracking if we consider that the base material is usually fully austenitic. In our own practice we prefer to aim at about 6 to 8% ferrite to avoid this possibility. The principal objection on the part of the authors to the presence of ferrite in the structure appears to be its transformation to sigma with resultant loss in room temperature ductility after exposure to temperatures of 1100° F. and above. No evidence has been presented that sigmatization results in embrittlement at elevated or service temperatures. It should be recognized that the austenitic weld metals in stress rupture testing at elevated temperatures usually fail in a brittle manner regardless of high room temperature ductilities. This observation may place some doubt on the value of room temperature ductility as a criterion to predict performance at elevated temperature.

The effect of heat treatment on the mechanical properties and microstructure of a 19 Cr–9 Ni Cb weld metal is shown in Fig. 2. These curves indicate that tensile strength reaches a maximum, and elongation, reduction and impact strength reach a minimum at 1300–1400° F. Full recovery of ductility and impact strength occurs at about 1700–1750° F. The photomicrographs shown at the top of this figure illustrate the dendritic pattern of the ferrite in the as-welded specimen and the almost complete agglomeration into ferrite pools after heat treatment at 1750° F. It appears that at 1750° F. ferrite and not sigma is the stable phase. Subsequent sigmatization of the heat-treated specimen does not result in drastic reduction of room-temperature ductility since the ferrite is now distributed in a much more favorable pattern. Figure 3 is a summary of 27 experimental weld metals showing mechanical properties before and after heat treatment at 1750° F., and plotted in order of increasing tensile strength. This heat treatment results in a loss of yield strength of some 10,000 psi., whereas the tensile strength, elongation and reduction remain essentially the same.

If we assume a yield strength of some 60,000 psi. in the as-welded deposit, it is conceivable that stresses of that same magnitude may exist in the joint. Effective stress relieving would not likely occur at the relatively low service temperature to which these alloys are sub-

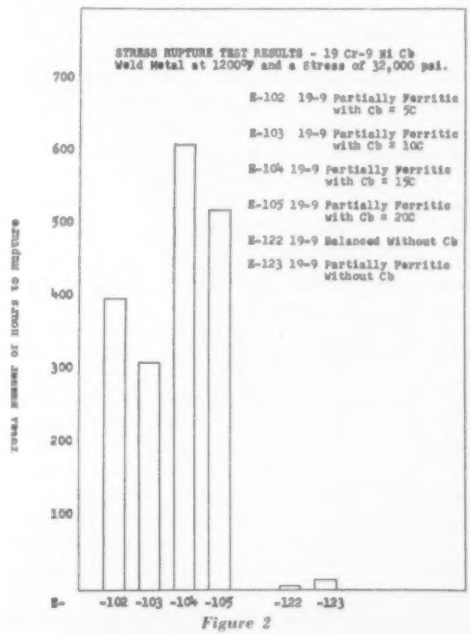
STRESS RUPTURE TEST RESULTS - 19 Cr-9 Ni Cb
Weld Metal at 1200°F and a Stress of 32,000 psi.
E-102 19-9 Partially Ferritic with Cb = 5C
E-103 19-9 Partially Ferritic with Cb = 10C
E-104 19-9 Partially Ferritic with Cb = 15C
E-105 19-9 Partially Ferritic with Cb = 20C
E-122 19-9 Balanced Without Cb
E-123 19-9 Partially Ferritic Without Cb
Total Number of Hours to Rupture
700
600
500
400
300
200
100
0
-102 -103 -104 -105 -122 -123

Figure 2

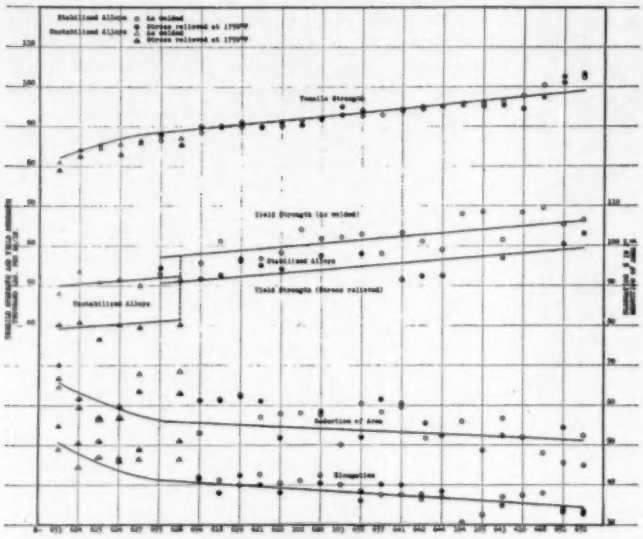

Fig. 3 As-welded and stress relieved (1750° F.) physical properties of partially ferritic 18 Cr–8 Ni and 18 Cr–8 Ni Cb weld metals

jected in steam piping, whereas a heat treatment at 1750° F. is expected to relieve about 90% of the existing stresses in the joint.

Thus, heat treatment of the welded joint provides a more favorable distribution of ferrite as well as an effective relief of stresses. We fully agree with the authors that the joint would probably perform satisfactorily in service without heat treatment, however, more experimental proof is needed before the heat-treatment provisions of the present A.S.M.E. Code requirements may be safely eliminated.

Discussion by F. W. Schmitz and M. A. Scheil

The authors are to be congratulated on the presentation of a well-developed and comprehensive paper. This paper is of particular interest to us since we have reached similar conclusions in the testing of $1^1/_2$-in. thick weldments in Type 347 stainless-steel plate stock; the subject weldments being fabricated with commercially available coated electrodes conforming to the A.W.S. series classification E-347-15.

A summary of our investigation, on the basis of heat treatments given for stress removal, reveals that the ductility of all weld metal tensile test bars is affected by the following variations:

1. Maximum ductility of 30% and over is obtained in the as-welded condition with ferrite content between 3 and 8% when no sigma is present.
2. Ductility varying between about 10 to 30% is obtained after heat treatment producing sigma contents from 5 to 1%.
3. Weld metal containing ferrite in the as-deposited condition does not always sigmatize to the full extent possible.
4. The size and distribution of the sigma phase vary the ductility. Larger particles of sigma in a segregated pattern are more effective in lowering ductility.
5. Variation of welding technique, such as the deposition of thin and thick weld layers and peening affects the weld ductility only in so far as the amount of sigma produced on heat treatment.

Applying the data, shown in Fig. 18, to test welds Nos. 1 and 3 we find that in the as-welded condition these welds contain ferrite in the amount of about 3.5 and 2.0%, respectively, while our calculations show test weld No. 2 to contain about 20.0% ferrite while in the same as-welded condition. The physical testing of welds in the as-welded condition resulted in percentage elongations, as measured by face bends, of 55.0 and 32.8% for test weld No. 1, 35.0% for weld No. 2 and 9.0% for weld No. 3. As noted, the micro cracks contained in the submerged-arc weld deposit of weld No. 3 is reflected in poor weld ductility.

After holding the 3 test welds at 1600° F. for 2 hr. followed by air cooling the data contained in Figs. 18, 20, 22 and 26 reveal that ferrite has transformed as follows: Test weld No. 1 now contains 2.5% ferrite and 1.0% sigma, test weld No. 2, 8.5% ferrite and 11.5% sigma and test weld No. 3, 1.5% ferrite with 0.5% sigma. It is felt that this tabulation, coupled with physical test results, is extremely important since through its application it is shown that a small percentage of sigma together with some ferrite is not deleterious to ductility. In addition, it shows that too much ferrite in the weld deposit is deleterious since a much greater percentage of sigma will be present after a stress-relieving heat treatment.

The above reaffirms some of the conclusions of the authors and surely emphasizes the importance of realizing what takes place during a short time stress-relieving heat treatment at 1600° F. We feel that this fact

F. W. Schmitz is Metallurgical Engineer, and **M. A. Scheil** is Director of Metallurgical Research, A. O. Smith Corp., Milwaukee, Wis.

should be stressed since it may be overlooked by many of us.

A study of Figure 30 revealed an abrupt change in the ductility of the 29 chrome–9 nickel–columbium submerged-arc weld after holding at 1100° F. for a period of only 20 hr. In this short period it is indicated that the percentage elongation, as measured by bend tests, has changed from 35.0%, in the as-welded condition, to 4.0% after holding at the 1100° F. temperature. The above is accompanied by a change in the amount of ferrite present, a change from our calculated 20.0% value to a value approximating 14.0%. Here again, a change in the ferrite content, coupled with an increase in hardness and a decrease in ductility, indicates the presence of the brittle sigma phase. The amount of this sigma phase would be approximately 6.0% since the ferrite content has changed in that order.

To us, the above again emphasizes the fact that the loss of ductility, due to the formation of the sigma phase, can and does take place after comparatively short exposure periods at temperatures as low as 1100° F.

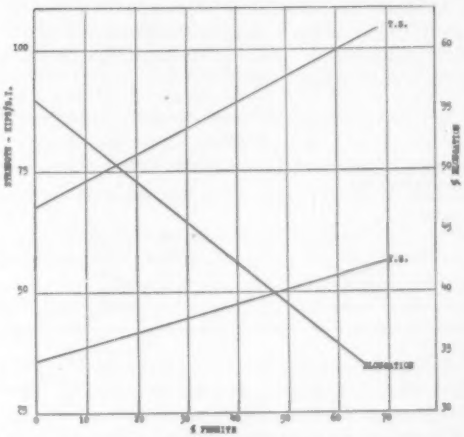

Fig. 1 The effect of ferrite on strength and ductility of cast A.C.I. CF-8C (annealed)

Discussion by V. T. Malcolm and Sidney Low

The authors are to be complimented for presenting the results of such an exhaustive research program on the welding of A.I.S.I. Type 347 stainless steel. The Research Laboratory of The Chapman Valve Mfg. Co. has also conducted appreciable research on Type 347 weld deposits and the cast grade of A.I.S.I. Type 347 (A.C.I. CF-8C).

Our experience, in both the laboratory and on production, confirms the authors' conclusions with respect to micro- and macrofissuring of weld deposits. However, in order to circumvent the difficulties, as pointed out by the authors, associated with the 29–9 Cb submerged-melt deposits high in ferrite; it is our practice to use A.I.S.I. Type 309S welding rod, either with Cb in the wire or added through the melt. Experience has proved that submerged-melt deposits made using this rod are free from all evidence of fissures. The weld deposits are also highly resistant to embrittlement following long time heating in the sigmatizing temperature range.

Figure 1 illustrates the effect of varying amounts of ferrite on the room temperature tensile properties of annealed A.C.I. CF-8C based on the results of a statistical analysis of approximately 100 heats. Since cast material and weld deposits are usually similar, it is not unlikely that a similar curve would be derived for weld deposits.

The rates of sigma formation, reported by the authors for the ferrite containing weld deposits far exceed rates observed in our laboratory. However, our work has been carried on using material lower in ferrite. Since the presence of sigma phase is quite readily detected by means of impact testing, most of our work has been conducted using both room temperature and elevated temperature impact testing. Figures 2 and 3 illustrate the effect on room temperature impact strength after heating both cast 18–10 Cb and 18-11 Mo for 500 hr. at temperatures 1000–1500 °F. Curves for both materials are included in order to compare a material that is relatively resistant to sigma formation with a material quite readily sigmatized.

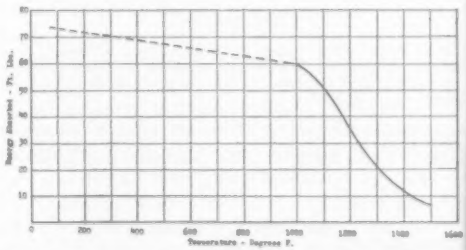

Fig. 2 Impact test results at 70° F. Keyhole notch charpy impact bar, exposure time—500 hrs., material—A.S.T.M. A157-44 grade C9° + Cb (3% ferrite)

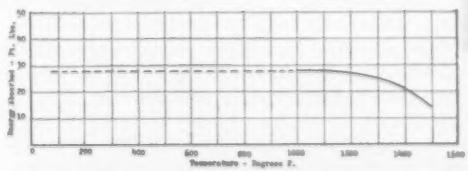

Fig. 3 Impact test results at 70° F. Keyhole notch charpy impact bar, exposure time—500 hrs., material—A.S.T.M. A157-44 grade C9° + Mo (11% ferrite)

V. T. Malcolm and Sidney Low, Director of Research and Research Engineer respectively, The Chapman Valve Mfg. Co., Indian Orchard, Mass.

Although the embrittling effect of sigma may be readily noted in Fig. 3, the effect is far more severe at room temperature than at elevated temperature. Table 1 illustrates this effect.

Table 1

Material: A.S.T.M. A157-44 Grade C9ᵖ + Mo (11% Ferrite)
Thermal history: Anneal 2100° F., heat 500 hr. at test temperature

Keyhole notch charpy impact test specimen

Test temperature, ° F.	*Energy absorbed, ft.-lb.*
1200	31.0
1350	30.0
1500	26.5

It may be noted that the toughness falls off rapidly after elevated temperature exposure (Fig. 3). The toughness at the operating temperature is not affected to anywhere near the same degree and equals, or exceeds, the toughness of ferritic low-alloy steels currently used for elevated temperature service.

Another interesting effect with respect to the ferrite content of 18–10 Cb castings and weld deposits is their behavior when subjected to the "Strauss" test. In order to insure the specimens will satisfactorily pass the bend test, following exposure to boiling acidified copper sulphate, it is usually necessary to have 3–9% ferrite present. This is true whether the material is as-cast, as-welded, annealed, sensitized or desensitized. If an adequate amount of ferrite is not present, misleading results may be obtained. The ferrite effect may completely overshadow the carbide effect and a specimen that in reality is completely resistant to boiling acidified copper sulphate may be rejected due to cracking directly attributable to inadequate ferrite content.

References

Malcolm, V. T., and Low, S., "Sigma Phase In Several Cast Austenitic Steels," presented at Symposium on Effect of Sigma Phase in High-Temperature Properties of Metals, A.S.T.M. Annual Meeting, 1950.

Malcolm, V. T., and Low, S., Discussion of "Thermal Shock and Other Comparison Tests Of Austentic and Ferritic Steels for Main Steam Piping," by W. C. Stewart and W. G. Schreitz, A.S.M.E. Trans., Vol. 72, No. 7, pp. 1043–1060 (October 1950).

Authors' Closure

The authors are most appreciative of the time taken by Messrs. Aborn, Jessen, Malcolm and Low, Schmitz, and Thomas in reviewing and discussing some of the more important and controversial points brought forth in this paper.

With respect to Dr. Aborn's question relative to the identity of the constituents in Fig. 31, the authors are certain that the dark etching constituent at the ferrite-austenite interface is sigma and not carbides. We make this statment only because a large number of samples were metallographically examined following a variable time at temperature, which afforded us an opportunity to follow the formation of sigma not only metallographically but also by magnetic means. To be sure, it would have been difficult if not impossible to state with assurance the identity of the dark etching constituent had we had only this specimen to examine and no means of comparing the relative magnetism of this specimen which was found to be considerably less than that of specimens in the "as-welded" condition. We also noted that the time required to etch this constituent was extremely short with the sodium cyanide and that carbides were attacked only after a more prolonged etch. Before preparing this closure we again examined the specimen of Fig. 31 together with others and feel confident of our original statement.

In making submerged-arc welds on circumferential joints in pipe of relatively small diameter, a large number of passes are usually required since the size of the weld bead must be such that it has fully solidified at a given location before the pipe has rotated too far from the flat position.

It is true, as Dr. Aborn has pointed out, that in view of the scarcity of columbium, substitutions for Type 347 must be considered. In considering the use of straight 18–8, however, the time-to-rupture of the 18–8 contrasted with 18–8 Cb with a Cb to C ratio of 5 to 1 is quite significant as given in Fig. 1 of Mr. Jessen's discussion of this paper.

The authors are indeed pleased to note Mr. Jessen's comments relative to the effect of heat treatment on the mechanical properties of the 19–9 Cb composition and his accompanying Fig. 2. The microstructures shown in this figure are quite comparable to those of Figs. 13 (*C*) and 15 (*A*) of our paper and based on the results obtained on the 29–9 Cb weld metal composition, we believe that the weld having had the 1750° F. heat treatment would sigmatize less rapidly than the as-deposited weld for reasons as originally presented and as further emphasized in Dr. Aborn's discussion. Believing that the ferrite will sigmatize in subsequent elevated temperature service, we concur fully with Mr. Jessen that globular ferrite is preferable to dendritic or columnar ferrite.

The comments offered by both Mr. Thomas and Dr. Aborn are welcomed as a logical answer to the change in slope of the 25-hr. curve of Fig. 19. We can concur with Mr. Thomas that 29–9 Cb wire can be used for submerged-arc welding of Type 347 base metal assuming the welded fabrication is to be used in the as-welded condition and is not subjected to elevated temperature service. It is conceivable too, that a deposit made using a 29–9 Cb analysis could be used for subsequent elevated temperature service, but this would necessarily require current, voltage, joint design, etc., wherein a considerable dilution of the weld metal, and therefore chromium, would be obtained and consistently maintained. In this connection, Mr. Jessen has, in his discussion, sounded a word of caution. Mr. Thomas, in questioning whether sigma phase is in any way related to microfissuring, indicates to us that we may have been not too clear in our discussion of Fig. 39, as we believe that no relationship exists whatsoever.

To further clarify our discussion on microfissures, we attribute these to low melting complex interdendritic segregates and Figs. 35, 36, 37, 39, 40 and 41 were presented in substantiation of this contention. The sigma phase shown in Fig. 39 was formed as a result of 25 hr. at 1600° F. although the microcrack was present prior to this heat treatment. This phase would not have been present, however, if metallic segregation had not originally paralleled this microfissure.

We would further comment that for a given weld metal composition, high preheat and relatively high welding current (and therefore a low cooling rate) could result in segregation which would result in microfissuring whereas manually deposited welds with low interpass temperature (and therefore a rapid cooling rate) with minimum segregation would produce welds free of microfissures.

We are pleased to note that our work is in general confirmation of that performed by the A. O. Smith Corp. and The Chapman Valve Mfg. Co. as discussed by Mr. Schmitz, and Messrs. Malcolm and Low. Point four of Mr. Schmitz's discussion can not be over-emphasized as the distribution of the sigma in many cases becomes of equal importance to the actual quantity present.

The experiences of Messrs. Malcolm and Low with the use of Type 309S welding rod are of interest to the authors and add further information to the knowledge of submerged-arc welding of Type 347 stainless material.

The Work of the Plasticity Committee of the Welding Research Council

THE Plasticity Committee was formed more than a year ago to deal with plasticity problems of importance and interest to the designing engineer. The Committee has held six meetings and in preparation for these meetings several subcommittees have met and formulated special reports. From the very outset the Committee decided that it would not embark upon a research program until it had a better idea of the problems involved.

The Committee feels that their activities over the past year may be of interest to others and a brief review of the deliberations of the Committee has been prepared by Wendell P. Roop, one of its members. The Committee is publishing this review because it would welcome the opinions of others interested in the plastic behavior of metals and associated problems.

Please address communications to W. Spraragen, Director, Welding Research Council, 29 W. 39th St., New York 18, N. Y.

When in wartime a number of ships broke in two, it led to great activity in analysis of the casualties, laboratory experiments, formulation of theories, conferences, symposiums and committees. This has now been going on for six years without producing any clear-cut body of new doctrine. No definite change in practice, in choice of material or in design and construction, can be cited which gives assurance against recurrence of the trouble.

A formidable amount of information and discussion has piled up, too much for ready assimilation. Major digressions have been made in search of systematic knowledge for its own sake, and this was necessary because more direct treatment of the problem had been inconclusive.

In all this, the Welding Research Council has had an important part, especially in ready and prompt publication. From the beginning, however, its Director of Research foresaw the need of drawing together and evaluating all these data for direct use. That is the reason for formation of the Plasticity Committee.

The first meeting was held Nov. 2, 1949, and a wide agreement among the members at once appeared. Ductility in steel needs not less but more emphasis than strength; the time has come for making it a major consideration in design. Each member elaborated this theme from his own experience and these thoughts were recorded in minutes which were circulated in the Council's Reports of Progress.

The question: What can be done? was hardly suggested at the first meeting beyond the point of agreeing that designers need help. However, letters were exchanged so that by the time of the next meeting, Feb. 16, 1950, a move could be made to formulate definite proposals for action. These turned out to be threefold.

Item 1 deals with availability of materials resistant to cold brittleness. It was said that more such materials exist than most mechanical engineers are aware of. Suggestions were made as to how this might be remedied and help was offered.

Item 2 relates to strain distribution in ductile flow.

It was said that we may hope for a book on this subject but that the present committee, or the Council, can do nothing in this field at this time.

Item 3 concerns the phenomenon of fracture. Here the facts are not yet known to any one. The remedy is free research under impartial supervision. A graduate fellowship with only the broadest limits as to subject was recommended.

At the third meeting, April 16, 1950, these proposals were discussed at length, but before passing to formal conclusions it was thought necessary to get a better statement of objectives; another committee was asked to prepare a declaration of principle. This, again, was handled in part by mail so that at the meeting of May 12, 1950, we were able to make notable progress toward definite action.

It was felt that some account of this progress should be given to a wider circle of persons interested in the work of the Council and that is the reason for the present communication. It is hoped that it will evoke comment, especially from active engineers who feel the need for something the committee may hope to supply.

Our purpose is, first of all, to keep out of trouble with cold brittleness; but also, beyond this, to make constructive use of the property of ductility. In order to do this, we must surely know more about it.

Inquiry has gone along three major channels. Each of these has cross-connections with the others; each is regarded by some persons as more "fundamental" than the others.

Channel 1. One of them postulates materials with assigned properties and asks about geometrical patterns of flow, using methods adapted from the theories of elasticity and strength of materials.

Channel 2. Another channel follows the hope for improved materials and asks how they may be obtained, and how recognized.

Channel 3. And still another heads for a solution of the problem of fracture in terms of physical constitution.

A threefold orientation of interest reappears again and again. Thus Item 1 corresponds to Channel 2, Item 2 to Channel 1 and Item 3 to Channel 3.

Again, a tentative list of "factors influencing lack of ductility" offered on May 12th is as follows:

(*a*) Design factors: (1) notch geometry, (2) size effect. This follows, in general, Channel 1, though much study has also been given to real materials.

(*b*) Environment factors: (1) temperature, (2) rate of loading. The nongeometrical nature of these terms puts them in the general course of Channel 2.

(*c*) Material factors: (1) chemical composition, (2) grain size, (3) metallographic structure, (4) segregation effects, inclusions. These follow channels 2 and 3.

Once more, the formal outline of subject classification in a bibliographic project of another agency has, as major headings:

(*a*) Fracture from the standpoint of mechanical metallurgy. This falls near the middle of Channel 2.

(*b*) Fracture from the standpoint of physical metallurgy. This coincides almost exactly with Channel 3.

(*c*) Fracture from the standpoint of engineering. This is in part closely parallel with Channel 1, but includes also matter pertinent to Channel 2.

However, the designations and content of these three broad projects in understanding may vary, the general distinctions involved are widely recognized. All are pertinent to the work of our committee, all are already the objects of major efforts, all must command our further attention.

None of them however, nor all three together, quite serve to define our purpose. We want now to move forward to a formal statement of that purpose. But instead of giving a tentative version of such a formal statement we will now describe a situation which, again on May 12th, held our unanimous interest.

From the time of the first service fractures their brittle nature has seemed important, as though, if the steel had not been predisposed to brittleness, the casualties would not have occurred. Early laboratory tests were aimed at reproducing this brittleness and finding what caused it, since medium steel had been regarded as a ductile material. If a single cause must be named, it is cold; the phenomenon is known as cold brittleness.

It was hoped that for each kind of steel, according to chemistry, mill practice, heat treatment, a temperature limit could be set, above which the steel would not be brittle and a ship built of it would be safe. But this hope has not been realized. The results of test are widely scattered and different tests give different results. Perhaps this can be cured by more apt interpretation of the test data, but so far this has not been done.

Recently it has become clear that the correlation between cold and casualties works only one way. Most casualties occur in the cold, but cold is not enough to cause casualties; almost wholly necessary, but not at all sufficient. Something prevents the possible event from taking place.

A builder whose structures have never shown cold brittleness feels justified in the opinion that something about his practice gives him this immunity even though he does not know what it is. This, however, is not acceptable as an attitude for all of us unless we are willing to take incalculable risks every time we change the details of construction practice.

Another situation of fact also discussed on May 12th relates to the localization of flow about a notch. Here the situation is more intricate and the facts are less clear than before; they are concerned with the transition from ductile to brittle action as the temperature is reduced, and with the way in which this is affected by notch acuity and by width (space between the notch and the boundary to which the crack advances).

Let us judge the transition by the appearance of the fracture surface. It is said to be a fact that in narrow specimens the position of this transition on the temperature scale is not much affected by acuity in the machined notch so that the same result is obtained from a variety of different types of small specimen.

This may be explained by reference to localization of strain. It is in the small region about the apex of the

notch that lack of ductility in the metal starts a brittle fracture. But for a wide range of acuities in the machined notch the final rupture is preceded by formation of a small natural crack. Only at a later stage in the process is it decided whether or not the crack will advance in the brittle mode, and this decision is made under the conditions existing at the apex of the natural crack.

It is suggested that an appropriate question for the committee to ask would be:

How may the fact just cited be evaluated and applied to conclusions about an extended structure, where the boundary toward which the crack will advance may be at an indefinite distance?

Experiments with internally-notched specimens in the form of wide plates in tension show that as width increases on constant thickness the transition temperature definitely rises, quickly in narrow specimens, more slowly as width increases. A reason for this may again be seen in terms of the localization of strain at the apex of the notch. In the wider plate this localization is more severe because of the presence of more metal at a greater distance from the notch. In the early stages of loading, strain at the edge of the plate is more uniform in the wider plate; the extra metal serves to increase the uniformity of strain in the metal further from the edge, so that the rise in intensity of strain near the notch is steeper in the wider plate. The palliative action of plastic flow around the notch is reduced and the influence of the notch in favoring brittleness is increased.

The transition in an extended structure, other things being equal, thus lies higher on the temperature scale than in a small specimen.

In a third situation the crucial fact cannot be cited with full assurance because it is still subject to further inquiry. If we take it as a hypothesis and if it is found to be correct it will furnish a good basis for an engineering theory of fracture.

A preliminary fact, however, is already accepted, namely, that the natural crack which appears in the early stages of most static tests on notched specimens has the characteristics of a ductile fracture, even at temperatures low enough so that the ultimate rupture will be regarded as brittle. This preliminary ductile stage seems to be reduced by low temperature; great width has a similar effect, as in the service fractures of full-scale ships, which thus behave like small specimens at a lower temperature.

On the other hand, in small specimens at intermediate temperatures, the brittle choice is made at the apex of a natural crack formed by a ductile process. There is thus a resemblance between the effect of a very fine crack and the effect of a very low temperature.

The reason for this resemblance may be said to lie in the degree of strain localization; low temperature hardens the hard spot at the apex of a notch in the same way as does increased acuity. Coupled with this increased localization is a high degree of equalization among the three principal tensile components of stress, in one word, of "constraint." It is everywhere accepted that such a state of stress would be unfavorable to deformation and that when it prevails high intensities of the tensile-stress components will be accompanied by low values of energy absorption.

The engineering hypothesis now put forward is this:

That in situations of high constraint, local fracture occurs when the local value of energy density (as in inch-pounds per cubic inch) reaches a definite limiting value; and that this limit may be evaluated in a test like that of tension in an unnotched bar, in which constraint may be much lower (even on the axis of the bar) and flow occurs much more freely.

Or, in fewer words:

Even when constraint is high, fracture occurs when local energy density reaches a critical value depending on the material.

If the committee can now achieve a statement of purpose which will be widely understood against a background of these and other situations of fact, then the first and greatest step will have been taken.

Announcement of Predoctoral Fellowships on the Fundamental Sciences Related to Welding

Administered by the WELDING RESEARCH COUNCIL

in the name of Chicago Bridge & Iron Co., International Harvester Co., The Linde Air Products Co. and other Companies

IT IS the purpose of these Fellowships to provide young men who have demonstrated marked ability an opportunity to conduct basic research in the applied sciences related to welding and its closely allied fields. These Fellowships are supported by the International Harvester Co., Chicago Bridge Iron Co., The Linde Air Products Co. and others. Any University desiring to apply for one of these Fellowships should indicate the type of problem which the University wishes to undertake, the name of the faculty adviser, and a biographical sketch and complete information in regard to the Fellows as indicated later on in this brochure.

QUALIFICATION OF APPLICANTS

A Fellow must be a citizen of the United States who has demonstrated ability and aptitude for advanced work, and who has training in welding, or in the fundamental sciences related to welding equivalent to at least a Bachelor's Degree in a university of recognized standing.

FIELDS OF STUDY

It is expected that these Fellows will work on scientific problems related to welding, or in the fundamental sciences related to welding.

FELLOWSHIP ACTIVITIES

A Fellow will be required to devote his entire time to advanced study and research, except that he may, when approved in advance by the Board, do a limited amount of teaching at an appropriate level as a part of his training. A Fellow may not receive aid from another fellowship, scholarship or similar grant during the tenure of the fellowship unless approved by the Board.

CONDITIONS OF APPOINTMENT

The fellowships will be awarded at a regular meeting of the Fellowship Board.

To receive consideration for tenure during any academic year, applications must be filed on or before May 1st, preceding the academic year. Awards will be announced about July 1st preceding the academic year.

A candidate for a Fellowship shall be nominated by an institution in the United States which is prepared to furnish equipment and supervision suitable for the types of problem mentioned under "Fields of Study." Nominations for a Fellowship grant should be forwarded by a responsible official of the institution concerned and must be accompanied by complete college transcript, photograph of the proposed Fellow and a plan for study and research. In the event that it is not possible to lay out a detailed program for study at the time of application, a general indication should be given of the method and procedure that will be followed. This should be supplemented with a definite plan two months after the beginning of the academic year. The plan should include the name of the research adviser who will guide the course of the research work.

The proposed Fellow may be requested to appear before the Board, or its designated representative, for a personal interview. In such cases, travel expenses will be paid by Welding Research Council.

The initial appointment will be for one year. Reappointment may be made upon application for a second year, and in exceptional cases for a third year, when warranted by the progress and accomplishments of the Fellow. A fellowship appointment is subject to the condition that neither the general plan for study and research, nor the faculty adviser shall be changed without the consent of the Board. Unless otherwise arranged, tenure will begin in September.

A fellowship does not carry any commitment on the part of the Fellow, or the supporting Companies, with regard to employment.

GRANTS

The annual fellowship stipend, which will be determined in every case by the Fellowship Board, will be a maximum of $1800 for a single man, and $2500 for a married man, except as noted below. An added amount not to exceed $1000, may be provided annually to the institution to which each Fellow is assigned for tuition, special fees, travel or necessary supplies. In the case of successful applicants who are eligible for benefits under Public Laws 346 or 16, the fellowship award will be supplementary to such benefits and will carry an adjusted stipend to be determined by the Board.

LOCATION OF WORK

The fellowships will be awarded to individuals for study and research in this country. The faculty adviser shall be approved by the Board.

REPORTS

The Research Fellow will be expected to submit semi-annual progress reports. Upon the termination of a Fellowship, each Fellow will be required to submit to the Board a detailed report of the principal results of his research and Fellowship experience.

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It is understood that the results of work carried on by a Fellow, whether in the form of a doctoral thesis or not, shall be available to the public through accepted scientific channels without restriction. Each publication of results of an investigation made during the tenure of the fellowship should include a statement indicating that the research was conducted while the author was a Chicago Bridge & Iron Co., International Harvester Co., The Linde Air Products Co. or other Research Fellow in welding under the Welding Research Council. If publications resulting from work under a fellowship appear the author is expected to furnish 20 copies of each paper to the Fellowship Board of the Welding Research Council.

APPLICATIONS

Applications or requests for additional information, should be addressed to the Welding Research Council, 29 West 39th Street, New York 18, N. Y.

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Relative Strain-Aging Tendency of Weld and Base Metal

An investigation to separate the relative tendency of the weld-metal heat-affected zone and base metal to change ductility after straining and aging

by R. W. Fountain and R. D. Stout

INTRODUCTION

THE tendency of low-carbon steels, such as the structural grades, toward strain aging is well known. After such steels have been strained, an aging period of days or months at room temperature or much shorter time at elevated temperatures such as 400° F., results in an increase in tensile strength, reduced ductility and noticeably, a loss of notch toughness. The thermal cycle of welding has been found to encourage aging of this type.

A number of investigations[1-3] has shown that base metal heated by the welding operation to a temperature in the neighborhood of 900–1200° F. will show reduced notch toughness presumably because of aging effects.

A somewhat different phenomenon has been observed by Jackson and Luther[4] and by Flanigan.[5] When bead-on-plate welded specimens were notched and bent after increasing time intervals, a gradual improvement in bending ductility took place up to about 30 days after welding. Flanigan reported that prestraining followed by aging for 3 to 10 days produced a noticeable loss in ductility in welded plates. After 30 days no such loss was detectable. The reduced ductility was ascribed to strain aging of the weld metal, in which the initial cracking during bending was reported to be located. The type of test used did not, however, preclude the possibility that the base metal was participating in the aging effect.

OBJECT OF THE INVESTIGATION

In the present investigation, a preliminary series of tests was conducted to obtain an indication of the relative tendency of the weld metal and of the base metal to change in ductility after straining and aging. The tests were designed to measure separately the behavior of weld metal and of base metal, and further to show whether the heated zone was a contributing factor to the phenomenon.

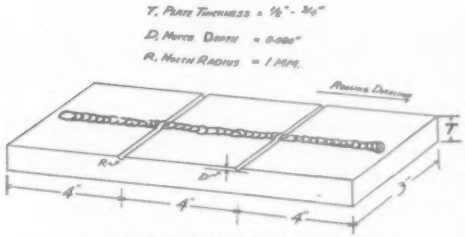

Fig. 1 Longitudinal bend specimen

EXPERIMENTAL PROCEDURE

The longitudinal notched-bend test shown in Fig. 1 was used in this investigation. In several tests described later, the notch depth was increased to as much as twice the normal value.

The steel used throughout the investigation was ¾-in. thick semikilled plate analyzing:

	%
C	0.18
Mn	0.50
Si	0.08
P	0.014
S	0.027

with a McQuaid-Ehn grain size, 2–4. The plate was welded in the as-rolled condition.

Welding was performed with an automatic welding head, and a lathe carriage was used to obtain the desired travel speeds. Two types of welded specimens were prepared. In the first type, the weld was a single

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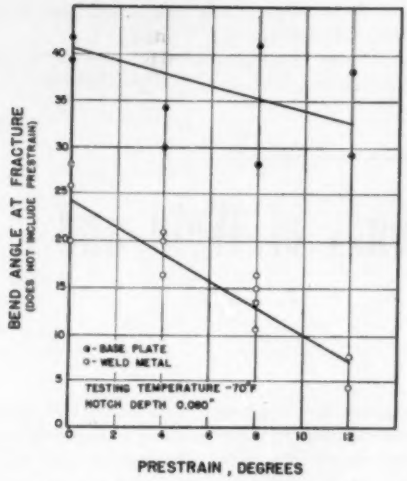

Fig. 2 Effect of prestrain on the ductility of base plate and all weld metal specimens having a notch depth of 0.080 in.

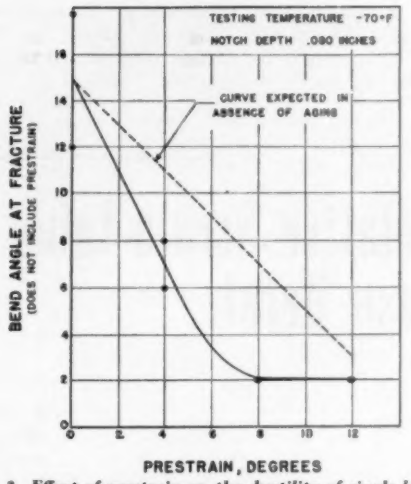

Fig. 3 Effect of prestrain on the ductility of single bead on plate specimen having a notch depth of 0.080 in.

bead-on-plate deposited at the center line of the plate parallel to the 12-in. dimension. The second type contained two welds which ran parallel to the 3-in. dimension at points coinciding with the location of subsequent notching. These welds were deposited in two passes in a machined groove $^1/_4$ in. deep in plates originally 12 in. square. Welding conditions were as follows:

Single bead: $^3/_{16}$ in. E6010, 160 amp., 8 in./min.
Double pass weld: $^1/_4$ in. E6010, 275 amp., 8 in./min.

The double-pass welds were prepared to provide specimens in which the notch would be entirely within weld metal. The bottom of the first pass extended almost to the center line of the plate thickness, while the second pass extended about 0.200 in. below the plate surface. In the single beads-on-plate, penetration was 0.100 in. below the plate surface.

Prestraining was introduced by placing the notched specimens in a jig with a 7-in. span and bending them measured amounts with the notch in tension. One day elapsed between welding and prestraining.

Aging was carried out at room temperature, after bending, for a period of 3 days.

Testing was carried out on the same jig used for prestraining. The testing temperature was obtained by a dry-ice and alcohol bath from which the specimen was removed for testing. The testing-machine head moved at 2 in. per minute. The ductility of the specimen was measured in terms of the bend angle at which the load dropped to half of the maximum attained during testing. In all but a few tests, this angle was identical to the bend angle at maximum load, since the fracture was always cleavage in its mode except for tests performed above 70° F.

CONDITIONS INVESTIGATED

The following test conditions were chosen for investigation:

1. Effect of 0, 4, 8, and 12 degree prestrain and aging on (*a*) unwelded base plate; (*b*) plate with notch entirely in weld metal; (*c*) welded bead-on-plate with standard notch and (*d*) bead on plate with notch 0.100 0.120 and 0.160 in. deep.

2. Transition temperature determination after 0 and 4 degree prestrain and aging: (*a*) plate with notch

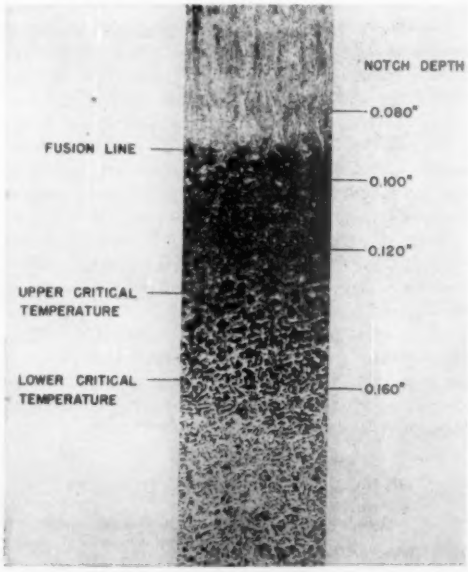

Fig. 4 Microstructure of bead on plate specimen

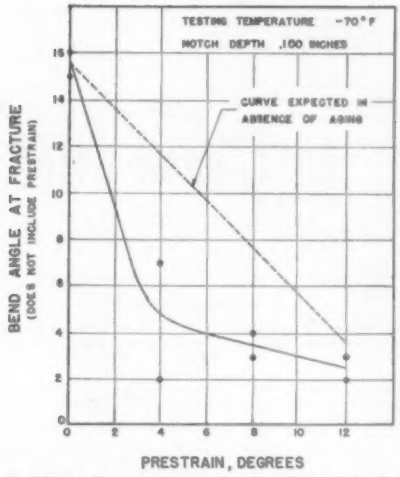
TESTING TEMPERATURE -70° F
NOTCH DEPTH .100 INCHES
CURVE EXPECTED IN ABSENCE OF AGING
BEND ANGLE AT FRACTURE (DOES NOT INCLUDE PRESTRAIN)
PRESTRAIN, DEGREES

Fig. 5 Effect of prestrain on the ductility of single bead on plate specimen having a notch depth of 0.100 in.

in weld metal; (*b*) bead on plate with notch 0.080 in. deep and (*c*) bead on plate with notch 0.120 in. deep.

In Part 1, all testing was conducted at −70° F. except for specimens notched 0.160 in. deep. With the deep notch condition, the testing temperature was raised to 0° F.

DISCUSSION OF RESULTS

In Fig. 2 the behavior of unwelded plate and of specimens with the notch entirely in weld metal is shown. In the absence of aging, prestraining can be expected to lower the bend angle during testing by an amount

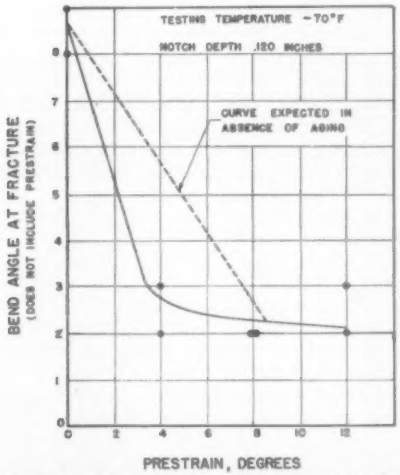
TESTING TEMPERATURE -70°F
NOTCH DEPTH .120 INCHES
CURVE EXPECTED IN ABSENCE OF AGING
BEND ANGLE AT FRACTURE (DOES NOT INCLUDE PRESTRAIN)
PRESTRAIN, DEGREES

Fig. 6 Effect of prestrain on the ductility of single bead on plate specimen having a notch depth of 0.120 in.

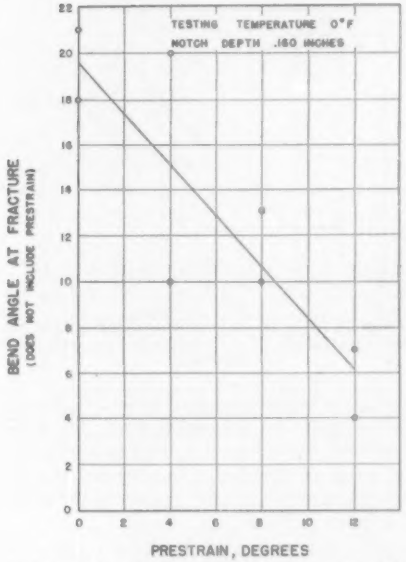

Fig. 7 Effect of prestrain on the ductility of single bead on plate specimen having a notch depth of 0.160 in.

equal to the degree of prestraining. If aging effects occur, they will reduce the bend angle below this expected level. No aging tendency of the unwelded plate or the weld metal is evident in Fig. 2.

The effect of prestraining and aging on specimens containing bead-on-plate welds is shown in Fig. 3. A considerable response to aging is indicated by the drop in bend angles below the expected curve.

Since specimens with the notch all in weld metal and those from unwelded plate both showed no susceptibility toward aging, while the specimens in which the notch crossed heated zone structures showed definite strain aging, it appeared that the heated zone is the area that contributes the major part of the susceptibility. Additional specimens were welded with a bead-on-plate and notched 0.100, 0.120 and 0.160 in. deep. The 0.100-in. deep notch was chosen to eliminate just

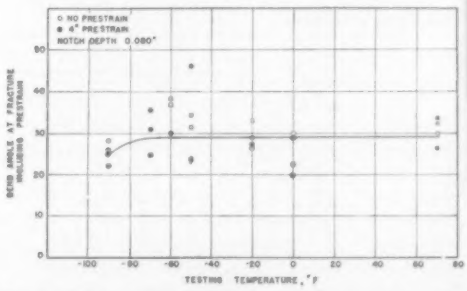

Fig. 8 Effect of prestrain and temperature on ductility of all weld-metal specimen having a notch depth of 0.080 in.

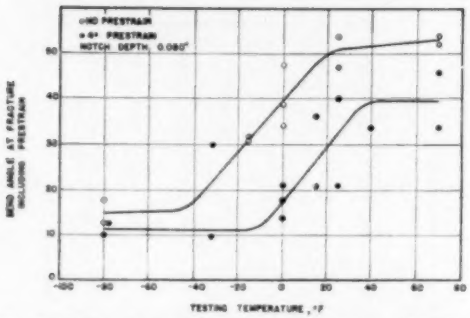

Fig. 9 Effect of prestrain and temperature on ductility of single bead on plate specimen having a notch depth of 0.080 in.

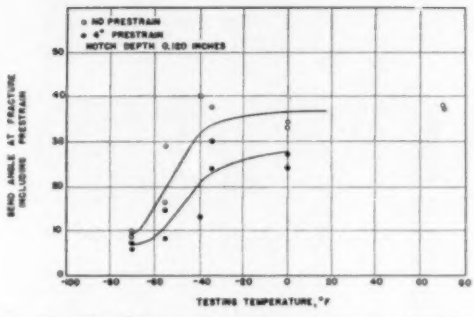

Fig. 10 Effect of prestrain and temperature on ductility of single bead on plate specimen, having a notch depth of 0.120 in.

weld metal from the notch; the 0.120-in. notch removed the coarse grains of the heated zone; the 0.160-in. notch left only metal heated to temperatures under the critical range of the steel. The location of each of these notch roots with respect to the heated zone structures is shown in Fig. 4.

From the test results given in Figs. 5–7 it will be seen that the structures remaining under the 0.100 and 0.120-in. notches showed strain aging; but with a 0.160-in. notch, aging disappeared. Thus there is further evidence that the heated zone is the area undergoing changes due to aging.

The effect of strain aging on the notch toughness of steel is best measured by changes in the transition temperature accompanying it. In Figs. 8–10 is shown the effect of 4 degrees prestrain with 3 days aging on specimens of welded plate having (*a*) the notch in weld metal, (*b*) the notch 0.080 in. deep across a bead weld and (*c*) the notch 0.120 in. deep across the bead weld. Figure 8 indicates that the weld metal is unresponsive to prestraining and aging. In Fig. 9 a noticeable raising of the transition temperature of the bead-welded plate has resulted from prestraining and aging. Both weld metal and heated zone are exposed to the root of the notch in this series. In Fig. 10, results are shown for a notch depth, 0.120 in., sufficient to remove all weld metal from the notch root. The transition temperature is again higher after prestrain and aging. The heated zone here again appears to be the area which is responding to strain-aging treatment.

From these tests it appears that further work is required to establish the conditions under which strain-aging effects are present in weldments and to determine which zone or zones of the weld are responsible for the effects observed. It is not possible to assign responsibility to the weld metal alone.

SUMMARY

1. A loss of ductility and notch toughness in welded plate due to prestraining and aging has been reproduced, using the slow notched-bend test.

2. When the notch is placed entirely in weld metal, the above effect is absent. Specimens with notches containing both weld metal and heated zone display the effect, as do specimens notched deeply so as to eliminate weld metal from the root. Unwelded plate is not susceptible to the effect. It appears therefore that the heated zone rather than weld metal is responsible for the loss of ductility and toughness caused by this type of prestraining and aging.

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A Notch-Bend Test

Development of a notch bar-bend test and applicability to mild, chromium and stainless steel. Interesting observations on stainless steels

by Carl A. Zapffe and Clee O. Worden

SUMMARY

AN EARLIER specially designed bar-bend test is modified by means of notching the specimen, thereby greatly increasing the applicability and sensitivity of the test to include virtually all steels, and under most constitutional conditions. Several notch variations are tried, and a particularly effective and simple type is adopted. The study then proceeds with a general testing program for mild steel, chromium steel and stainless steel, exploring notch bendability as an indicator of important mechanical properties.

Covering nearly every standard commercial grade of stainless steel, the data afford particularly interesting observations on these alloys. The effect of carbon content in Class I steels, of chromium content in Class II, and of sulphur and selenium additions to all free-machining modifications is evaluated. The nature of notch sensitivity in the ferritic Class II steels is also illustrated by fractographs. Particular interest attaches to a comparison of the stabilized austenitic grades, Types 321 and 347, in which Type 321 demonstrates a superiority when either cold drawn, annealed or stabilized, equality of 321 and 347 only being attained after an extended stabilizing treatment. Some attention is also paid 475° embrittlement in Type 446, the notch-bend test detecting a decrease in bendability within the first 30 min. of treatment, whereas many hours or days are necessary to produce detectable brittleness with unnotched specimens.

INTRODUCTION

In a recent publication[1] a special bend test was described, designed for quantitative measurement of the bendability of metals on the basis of a constant-rate single-bend stressing of a round bar around a fixed radius. It was applied to the Class I* martensitic stainless steels with good results, and later succeeded in disclosing some surprising effects of steam in heat-treating atmospheres.[2, 3]

Nevertheless, this test did not succeed in fracturing any of the Class III austenitic grades, nor any of the Class II ferritic steels except when especially embrittled.[4] Also, the Class I grades fractured for the most part only when in the hardened condition.

To increase the sensitivity of this test, various types of notches were later applied to the specimens. The present paper (*a*) discusses the effect of this notching, (*b*) derives a simple notch technique leading to data which are reproducible and of such high sensitivity that virtually all steels are susceptible to the test and (*c*) applies this test to a general coverage of steels, with particular attention paid the stainless steels.

TEST METHOD

In Fig. 1, the head of the bend machine is shown. Structural details can be furnished by the authors on request; but here it will suffice to show the face plate (*A*) of $^3/_4$-in. steel, 16 in. on a side, covering a casing 20 in. high in which are contained the $^3/_4$-hp motor and driving mechanism. This face plate is drilled at its center to receive a $4^1/_2$-in. dia. solid steel drive shaft (*B*) geared down to a rotation of 5° of arc per second.

Mounted upon the face of the shaft is a replaceable die (*C*), drilled to receive a 1-in. length of the 4-in. specimen. On the edge of the die is a machined radius (*D*). All tests to be discussed here concern $^1/_4$-in. round stock and a bending radius of equal size, although a range of specimens and dies can be used.

Over the projecting end of the specimen a sleeve (*E*) is placed which carries the test piece around the radius and seats itself at full-bend position within a recess (visible on the far side of the die in Fig. 1 as a curved profile). This sleeve presses against the spring plunger of an electric clutch (*F*); and, when failure of the specimen reduces the compression on this spring, the clutch automatically stops the motor. Rotation of the shaft

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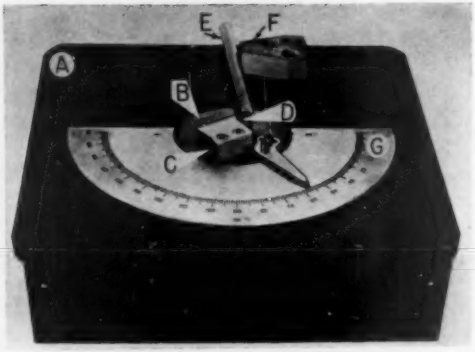
* Terminology following current book: *Stainless Steels*, Am. Soc. Metals, 368 pp. (1949).



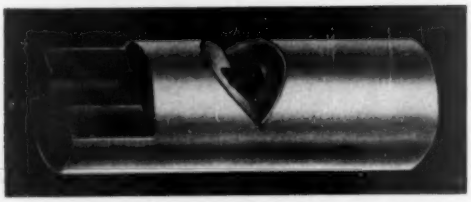


Fig. 1 (Above) Head of bend machine; (below) detail of notching guide

ceases so instantaneously that no correction for coasting is necessary. A pointer then indicates the angle on the inscribed brass semicircle (*G*).

In the present study, this same test was used, except that a notch was added to the tension side of the specimen and the sleeve was slightly altered to provide a more snug fit. Two principal notch types were investigated: (1) saw and (2) file. The notches of the first group were cut with jeweler saw blades:

Designation	*Width, in.*
0	0.012
2/0	0.010
5/0	0.009
8/0	0.007

Differences in depth of the notch will be described during the text. This type of notch has been studied by others[5–7] in regard to other types of testing.

As for the second type—file notch—there is also shown in Fig. 1 the detail of a sleeve of hardened tool steel made as a guide for notching. This is a 90° notch, to fit the edge of a rectangular file—preferred to a triangular file because of its sharper edge—and it allows a cut approximately 0.100 in. deep. The specimen is kept from rotating by a clamp fastened across the half section.

In brief summary, then, of the experimental procedure: (*a*) a specimen approximately 4-in. long is cut from $^1/_4$-in. round bar stock, degreased in carbon tetrachloride, and marked at one end—principally for purposes of closer temperature control if heat treated; (*b*) further treatment is administered as may be necessary, followed by cleaning and/or polishing with emery paper; (*c*) the marked end is inserted 1 in. into the die, with the notch on the tension side directly opposite the center of the bending radius, and with the base line of the notch as nearly vertical as can be judged with the eye; (*d*) zero adjustment is made on the scale for the point of initial stress, bending is begun and the angle of fracture obtained.

MATERIALS

Because of the accomplishment of the notch-bend test in adding the ferritic and austenitic grades of stainless steels to the list of materials subject to bendability measurements, the present study is principally directed toward a survey of stainless steel. However, several mild steels and low-alloy steels are included for comparison. Table I describes the specimens.

SELECTION OF NOTCH TYPE

In Fig. 2, bendability data are presented for Type 410 (heat 2 in Table 1) fractured under a variety of notch conditions. First, the unnotched bars, hardened at 980° C. (1800° F.) for 30 min. and oil quenched, failed near 25° of bend. All tempering treatments (here 475° C. and above) produced a full bend. In the original study,[1] Type 410 would not break even when fully hardened. The difference can be ascribed pri-

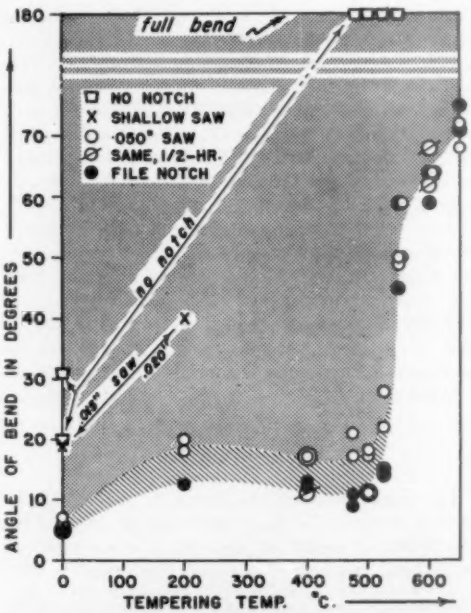


Fig. 2 Effect of notch type and depth on the bendability of Type 410 (heat 2) hardened from 930° C. and tempered as shown

marily to the higher carbon content of the present heat (0.13 vs. 0.10%), also the fact that an alteration of the sleeve in the present study to make it closer fitting has resulted in a slightly increased sensitivity for all specimens.

When a 2/0 blade and relatively shallow cuts of 0.015 and 0.020 in. are used (see Fig. 2), a slightly increased sensitivity is suggested. The first important results, however, are displayed by the 0.050-in. cut made with a 2/0 blade (white disks in Fig. 2). The material now fractures at only 7° in the full-hard condition; and its bendability remains in the 70° range even when tempered as high as 650°.

Surprisingly, further variations in notch dimensions are not particularly effective in changing the bendability. Increasing the depth of the 2/0 notch from 0.050 to 0.100 in., or decreasing the width from 0.012 to 0.007 in., scarcely shifts the curve:

Blade No.	*Notch width, in.*	*Notch depth, in.*	*Bend angle**
0	0.012	0.050	40, 48
2/0	0.010	0.100	50, 41
8/0	0.007	0.050	60, 49

* Specimens of Fig. 2 tempered at 550° C. for 2 hr. and air cooled.

The most important information in Fig. 2 concerns the data for a file-notch (black disks). These coincide with the saw-notch data for tempered specimens within the limits of experimental accuracy, and actually show an increased sensitivity for hardened specimens. Simpler to administer, the file notch also has the important advantage of applicability to steels of virtually any hardness, whereas the jeweler's saw is limited.

Accordingly, in all tests hereafter, the file notch is adopted as the standard technique.

OBSERVATIONS ON A MARTENSITIC STAINLESS STEEL (TYPE 410)

In addition to the information that it contains on notch conditions, Fig. 2 displays significant relationships between bendability and heat treatment for this typical martensitic grade, Type 410. The details of the treatment are as follows:

Harden....30 min. at 980° C., oil quench
Temper.... 2 hr. (exceptions noted), air cool

Both the saw-notch and the file-notch data agree in showing an upsweep at the 200° treatment; and they both indicate a subsequent downsweep between 400 and 525° C. The first is an expected result of stress relieving. The second probably expresses the unidentified but relatively well-known embrittlement attending the hardenable grades in this subtempering range.

Also on the graph are several points for tempering treatments of only 1/2-hr. No difference is noted between these and the 2-hr treatment at 600° C.; but a lesser bendability at 400° is indicated by the 1/2-hr. treatment in conformity with the known effect of tempering time at lower temperatures.

Table 1—Analysis of Specimens

Type No.	*C*	*Cr*	*Ni*	*Other elements*
		Weight, %		
		Carbon Steels		
S.A.E. 1020	0.19	...	...	...
S.A.E. 1112	0.12	...	...	S-0.20, Mn-0.74
S.A.E. 1113	0.11	...	...	S-0.28, Mn-0.76
		Chromium Steel		
A.I.S.I. 501	0.210	5.60	0.23	Mo-0.66
A.I.S.I. 502	0.100	5.81	0.25	Mo-0.56
		Stainless Steel: Class I		
A.I.S.I. 403	0.101	12.44	...	...
A.I.S.I. 410 (1)	0.102	12.63	...	...
A.I.S.I. 410 (2)	0.131	12.65	...	...
A.I.S.I. 410-C	0.175	12.45	...	...
A.I.S.I. 410-X	0.126	12.48	...	S-0.15
A.I.S.I. 414	0.107	12.32	1.68	...
A.I.S.I. 416	0.099	13.02	...	...
A.I.S.I. 420	0.392	13.27	...	...
A.I.S.I. 420-F	0.346	13.13	...	Se-0.23
A.I.S.I. 431	0.161	16.24	1.67	...
A.I.S.I. 440-A	0.647	17.43	...	...
A.I.S.I. 440-B	0.882	17.11	...	...
A.I.S.I. 440-C	1.02	16.88	...	...
		Stainless Steel: Class II		
A.I.S.I. 405	0.062	14.29	0.27	Al-0.26
A.I.S.I. 430 (1)	0.061	16.90	...	...
A.I.S.I. 430 (2)	0.072	16.97	...	...
A.I.S.I. 430-F	0.072	16.90	...	S-0.284
A.I.S.I. 442	0.136	20.75	...	...
A.I.S.I. 446	0.145	25.99	...	...
		Stainless Steel: Class III		
A.I.S.I. 301	0.090	17.30	7.36	...
A.I.S.I. 302	0.086	17.88	9.03	...
A.I.S.I. 303-S	0.059	17.78	9.18	S-0.264
A.I.S.I. 303-Se	0.059	18.24	9.60	Se-0.29, P-0.131
A.I.S.I. 304	0.053	18.13	8.99	...
A.I.S.I. 308	0.060	20.48	10.87	...
A.I.S.I. 309	0.117	24.19	19.89	...
A.I.S.I. 310	0.083	26.80	21.89	...
A.I.S.I. 316	0.101	17.63	12.55	Mo-2.41
A.I.S.I. 317	0.068	17.94	13.08	Mo-3.08
A.I.S.I. 321	0.049	17.55	9.52	Ti-0.50
A.I.S.I. 347	0.057	18.24	10.79	Cb-0.74
A.I.S.I. 325	0.126	8.69	19.31	Si-1.36
A.I.S.I. 330	0.057	15.00	35.37	...

OBSERVATIONS ON AN AUSTENITIC STAINLESS STEEL (TYPE 309)

An instance of the excellent sensitivity of the present test appears in Fig. 3 where a detailed heat-treating history is followed for a grade showing no frangibility under any condition in the work with unnotched specimens. Values on the ordinate refer to the condition as-received from the mill (cold drawn); and the specimens are then progressively heated to temperatures at 100° intervals up to 1200° C. in two series of 1/2 and 2 hr. at temperature, respectively, followed by quenching in water.

While there is little distinction to be made between the two sets of data, an indication of increased embrittlement is present for both series in the sigma range, from perhaps 500 to 800° C.; and the longer test shows slightly lower values within this range and more rapid recovery just above the range, as would be expected. No point can be made on the basis of these data alone,

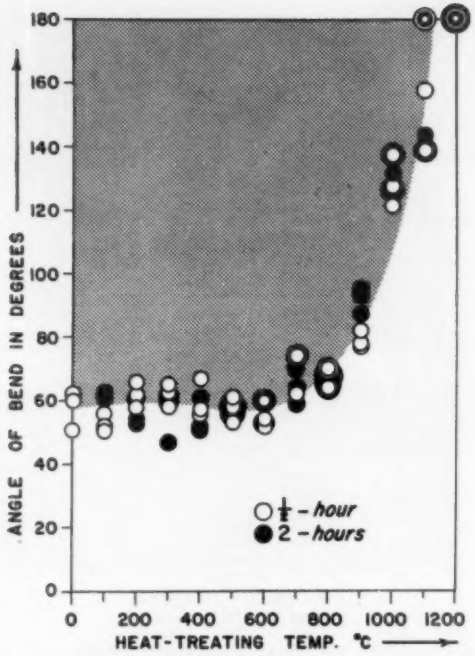


Fig. 3 Bendability of cold-drawn Type 309 stainless steel heat treated as shown

of course, but attention is called in passing because of the high sensitivity of the test later to be shown for the somewhat similar phenomenon of "475° embrittlement." A study of sigma lay outside the scope of the present program, but it invites attention from the standpoint of this test.

Final recovery of a full bend only after treatment at 1200° C. and the rapid climb of bend values in the range 900–1200° C. emphasizes that important ductility is to be gained from these highly alloyed grades by annealing at higher temperatures than those commonly used for "18–8." In fact, attention is called to the further gain between 1100 and 1200°, for this grade is susceptible to edge cracking during hot working, and 1200° C. lies above customary forging, also annealing, ranges.

GENERAL SURVEY OF BENDABILITY

All steels listed in Table 1 were next tested for bendability in their cold-drawn condition as received from the mill, both by the notched and the unnotched tests. In no case did an unnotched sample break.

On the other hand, all steels broke when notched with the file, with an exception for special cases of heat treatment. The fact that even the Class I steels did not break in the unnotched test follows from their nonhardened condition

Accordingly, the two charts in Figs. 4 and 5 express (*a*) the increased sensitivity afforded by the notch by the measure of the shaded column from the top of the chart (180° bend) toward the bottom, and (*b*) at least a qualitative comparison from one grade to another by the positions of their respective columns. It is important to emphasize that the data in Figs. 4 and 5 refer to structural conditions as-received from the mill and have no decisive value until the effects of coldwork on bendability can be exactly determined in later studies. Their principal purpose is to illustrate the sensitivity of the notch test and to provide at least an initial coverage of those stainless steels not subject to testing by the earlier technique.

Mild Steel

In Fig. 4, it is seen that S.A.E. 1020 is sensitive to the notch-bend test; and the very low angles of bend (20°) for the two free-machining grades display a marked susceptibility caused by the sulphur content—an effect which is observed throughout the work and lies safely beyond any interfering factors due to differences in specimen history.

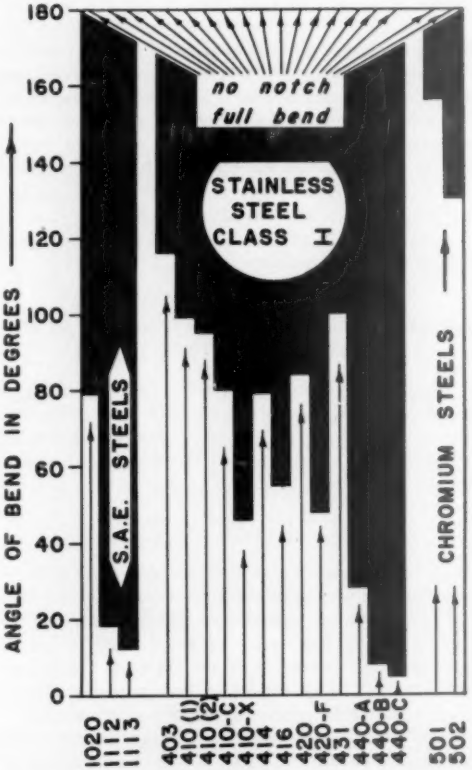


Fig. 4 Master chart for the bendability of mild steel, chromium steel and Class I stainless steel

Chromium Steel

In this same figure the two "4–6 chromium" steels, Types 501 and 502, show some of the best bendability values for the entire series.

Stainless Steel

Class I. Figure 4 contains a fairly complete survey of the commercial stainless steels hardenable by the martensite reaction—Class I—though only in the annealed and cold-drawn condition. The first seven reading from the left of this Class I group are all closely related to standard Type 410, and the variations of the columns express known properties with an interesting accuracy. Type 403, the best of the group on the basis of bendability, is the steam-turbine steel selected to close specification. Its carbon content (0.101%) is near the minimum for the seven. Heat 1 of Type 410 has a virtually identical carbon content (0.102%), but its slightly higher contents of S, P and Cr probably account for the indication of an inferior bendability.

Heat 2 of Type 410 has a considerably increased carbon content (0.131%); but its P and S are lower by an amount which very likely accounts for the lack of a sharper drop in bendability.

Increasing the carbon to 0.175% in Type 410-C drops the bendability appreciably; but most effective of all is the raising of S to 0.15% in Type 410-X. This grade strikes the lowest bend value for the group, and in spite of a relatively low carbon content (0.126%). The nickel addition in Type 414 leaves the standard behavior of Type 410 little changed. The data for Type 416, however, again specifically point to sulphur as a most damaging component so far as notch bendability is concerned. The bend values are as low as those for Type 410-X in spite of a carbon content of only 0.099%.

Proceeding to the cutlery grade, Type 420, one finds a comparatively good bendability, considering that the carbon content now approaches 0.40%. The addition of selenium to Type 420-F greatly reduces the bend value.

Type 431 is on a par with Type 410, and shows improvement over Type 414, which has a similar nickel content. It is like the Class II Type 430 both with respect to its two-phase structure and its bendability. On the other hand, a difference in the customary heat treating of these alloys previous to cold drawing prevents one from making too close a comparison.

Finally, the three "440-series" alloys show the expected behavior, the bend values all being very low, and decreasing with increasing carbon content.

Class II. On the left of Fig. 5, the ferritic Class II stainless steels are depicted. Type 405—the Type 410 base with a ferritizing addition of Al—is comparable in bendability to Type 430. Two heats of the latter are tested, and it may or may not be significant that the inferior bendability is exhibited by the alloy having a slightly higher carbon content.

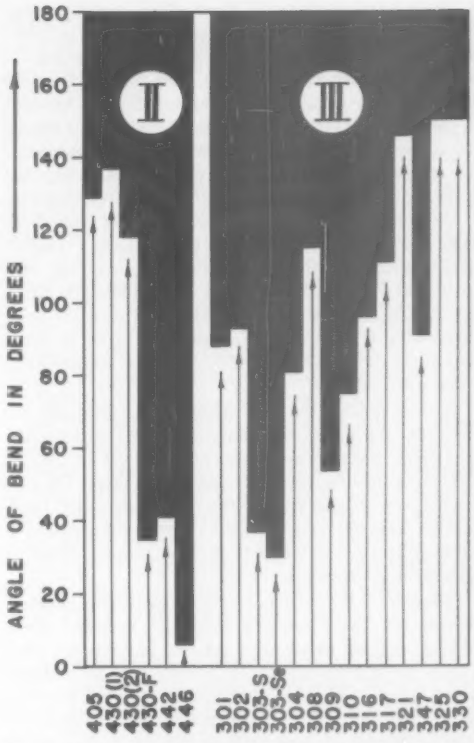


Fig. 5 Master chart for the bendability of Class II and III stainless steels

As for sulphur in the free-machining Type 430-F, the bendability is again greatly decreased. The point should be noted, for this free-machining modification constitutes a great proportion of the tonnage consumption for this popular grade.

Approximately equal to the sulphur in Type 430-F, so far as effect upon bendability is concerned, is the increased chromium content of Type 442. Even more pronounced is the effect of chromium in Type 446, a bend value being reached which is almost as low as that for 440-C.

In subsequent studies it will be advisable to establish some detailed relationships between bendability and other mechanical properties, for this property is certainly unique in some respects, and yet common in others. It closely follows measurements of plastic deformation (elongation, reduction of area) but also expresses elastic peculiarities. "Notch sensitivity," or the tendency to cleave instead of slip, is made particularly evident by the notch-bend test.

Thus, Type 446 has a ductility markedly superior to that of Type 440-C, but its notch-impact resistance is at best equal, and usually inferior. Accordingly, the data in Figs. 4 and 5 for these two grades reflect a clastic characteristic rather than a plastic, and the same is probably true for all the notch-bend data.

Fractographic study of these alloys has something to offer regarding distinctions in their response to deformation and fracture. The Class II alloys submit to such study particularly readily, and two fractographs are presented in Fig. 6 displaying a distinction between Types 430 and 446. In the upper fractograph a typical cleavage facet in Type 430 shows a traverse suggestive of a mediocre ship-plate steel[8]—fanlike, somewhat smooth, and lacking in crystallographic registrations.

In the lower fractograph, a typical facet from Type 446 shows an even flatter traverse, a more expansive cleavage (note difference in magnification) and—the principal characteristic—a maze of reticulated markings at sharply crystallographic angles. In fact, the cubic symmetry of the pattern proves this to be an (001) cleavage, intersecting {100} profiles contributing most of the design.

Consequently, the two fractographs illustrate the fact that the higher the chromium content of the ferrite the more liable it is to cleavage instead of to slip. This accounts for the notch sensitivity of the Class II steels and, specifically, for the decreasing notch bendability from left to right in the Class II group of Fig. 5. The effect has been followed elsewhere in some detail for binary iron-chromium alloys.[9]

Class III. Also in Fig. 5 are the bendability measurements for the Class III austenitic stainless steels. These show an excellent correlation with known properties even in the absence of a control of the coldwork administered previous to bending. Thus, one finds Type 301 very slightly inferior to 302, and both of the free-machining grades markedly inferior. The slightly lower bend values of Type 304, compared to 301 and 302, may reflect a somewhat unexpected property; but it may also be the result of a greater cold reduction in the mill.

Type 308, 309 and 310 show good respective positions, 309 being the least bendable, probably because of its tendency toward a ferrite content. The molybdenum grades, 316 and 317, are especially sensitive to "balance" of the alloy composition, which might account for the favored position of 317 here. The two stabilized grades, Types 321 and 347, show a contrast made particularly interesting by the present commercial shortage of columbium, and this will next be studied in more detail. The highly alloyed Types 325 and 330 show some of the best bendabilities among all steels tested.

AN OBSERVATION OF STABILIZATION

Because of the contrast in bendabilities of Types 321 and 347 shown in Fig. 5, several additional tests were run to ascertain whether this was due to actual differences in properties or simply to a difference in the cold reduction or mill handling. A set of samples, each grade in triplicate, was therefore annealed at 1040° C. (1905° F.) and water quenched.

Since one (Type 321) or both of these grades is often given a stabilizing heat treatment to increase fixation of the carbide, one set of the annealed samples was stabilized at 875° C. (1610° F.) for 1 hr; a second set for 4 hr.; and a set of the original cold-drawn specimens was also stabilized at 875° C. for 1 hr. All specimens were subsequently water-quenched. In addition to the two titanium and columbium grades, specimens of Types 301 and 310 were included in each set to serve as a comparison, since these more or less represent the low and high alloy extremes for the Ni-Cr series in which "sensitization" manifests commercially.

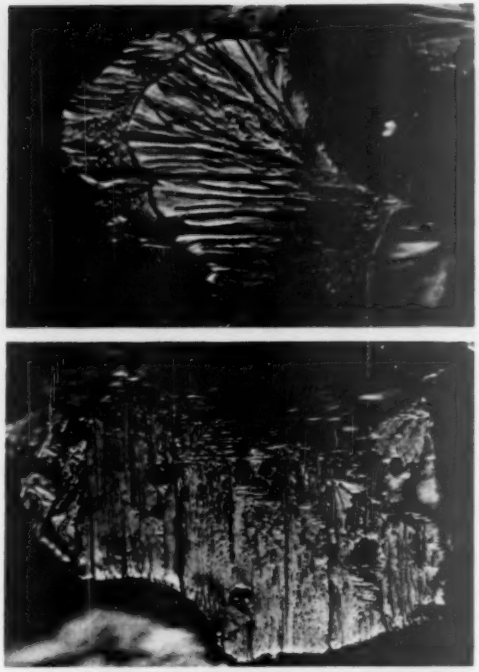


Fig. 6 Fractographs showing typical facets in Type 430 (above—1525 X) and Type 446 (below—850 X) accounting for increased notch sensitivity with increase in chromium content

In Fig. 7, the left-hand column repeats the respective "blank" bendability data for the four grades as indicated in Fig. 5. Types 301 and 347 are nearly identical in their cold-drawn conditions. Type 310 is slightly inferior; Type 321 is markedly superior. A 1-hr. treatment at 875° C. rather uniformly improves all grades except 301, which remains unchanged. The titanium-stabilized Type 321 now sustains a full bend for 2 out of 3 specimens. The columbium-stabilized Type 347 fractures uniformly near 110°.

Annealed at 1040° C. (1950° F.), all grades show marked improvement in bendability. All three samples of Type 321 sustain a full bend, and Types 301 and 347 each attain a full bend in 1 out of 3. Type 310 fractures uniformly near 140°, but the previous Fig. 3 suggests that this grade would also sustain a full bend if annealed at higher temperatures.

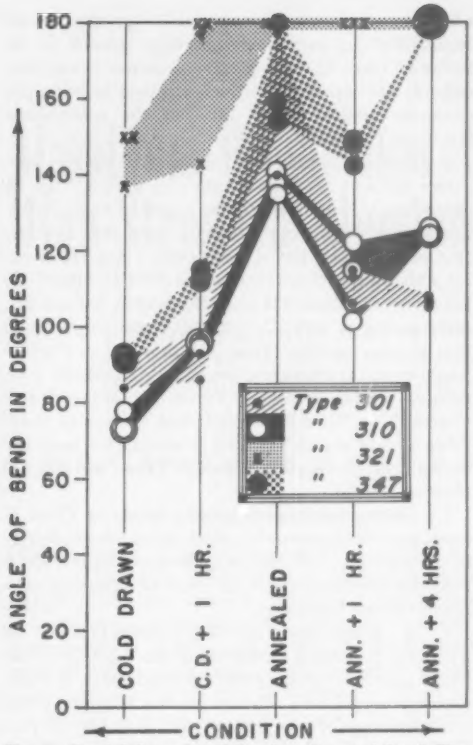


Fig. 7 Bendability of stabilized and unstabilized Class III stainless steels subjected to various annealing and stabilizing heat treatments

With the stabilizing treatment applied for 1 hr. at 875° to the previously annealed steels, Types 301, 310 and 347 all surprisingly lose in bendability. (See fourth column in Fig. 7). The titanium-stabilized Type 321, on the contrary, retains its full-bend values for all three specimens.

When this stabilizing treatment is prolonged for 4 hr., the columbium grade also attains a full bend for triplicate specimens (see righthand column). On the other hand, the extended treatment does little or nothing for Types 301 and 310. Whether the titanium grade is affected at all is not disclosed by the bend values, for all specimens continue to sustain a full bend.

These data are probably insufficient for disclosing the phenomena underlying the contrasting behaviors of these steels; but they do suffice to make further investigation promising. The two stabilized Types 321 and 347 have long been in competition, and their respective advantages and disadvantages have been much argued. The matter attains national importance in critical international periods because of a limited supply of columbium. The titanium grade has been criticized, among other things, on the basis of inferior fatigue properties, and excessive included matter; and its reactivity with the atmosphere during welding has so far prevented its use as welding electrode. Here, however, one observes a rather prominent advantage of Type 321 in regard to those properties disclosed by notch-bend values.

475° EMBRITTLEMENT

In Fig. 8, the notch-bend test is applied to the phenomenon of embrittlement occurring in the Class II ferritic stainless steels when heated in a temperature range near 475° C. Previous study of the effect using unnotched specimens only disclosed embrittlement after many hours or days of holding at temperature. The notched specimens, however, registered decreased bendability within the first half-hour, as shown in the figure. The two sets of disks refer to two sets of Type 446 stainless steel specimens, one previously annealed at 820° C. (1510° F.) for 1 hr. and air-cooled, the other at 1000° C. (1830° F.) for 1 hr. The higher annealing temperature has reduced the bendability—as might be expected from the grain growth and improved cleavage characteristics illustrated in the fractographs of the previous Fig. 6.

Although the blank values for the lower annealing temperature are more scattered, and the data in early embrittling periods erratic, after 2 or 3 hr. the bend-

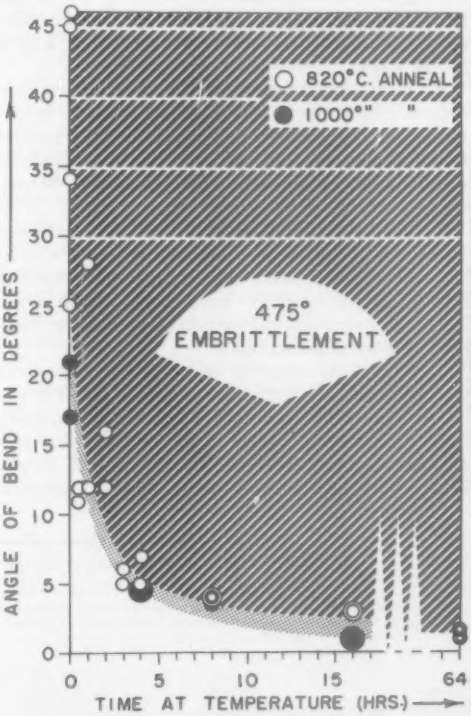


Fig. 8 Demonstration of the extreme sensitivity of the notch-bend test to the phenomenon of 475° embrittlement in Type 446 stainless steel

ability readings are reproducible and low for both series. Certainly the failures at angles of only 1 and 2° in the extended tests are remarkable, for glass would be likely to do as well. This phenomenon of 475° embrittlement is therefore an extremely important one for these steels if they are ever to be subjected to notch-type stressing during or after exposure in this temperature range. The matter will be considered in further detail in another paper,[4] and is only touched upon here because of the effective demonstration provided by the test under discussion.

CONCLUSION

Effective modification of the specially designed bend test earlier described for rod and bar has been afforded by the addition of a notch, and the results of this exploratory investigation of a number of steels, especially the stainless steels, permit the following conclusions to be drawn:

1. A notch of sufficient depth added to the tension side of the bar in the constant-rate single-bend test greatly increases the scope of the test to include virtually all steels, and in most of their constitutional conditions.

2. A notch made 0.10 in. deep with the corner of a rectangular file, using a sleeve of hardened tool steel as guide, provides reproducible data and allows wider utility and simpler application than notching with a jeweler's saw.

3. With a file notch, Type 410 stainless steel loses its ability otherwise to bend a full 180°, and its notch-bendability measurements then disclose the general results of stress relieving and tempering and indicate in addition a subtle embrittling effect occurring in the subtempering range of 400–525° C.

4. Similarly, the otherwise unbreakable austenitic grades readily fracture when notched, and data for Type 309 stainless steel show a beneficial effect of annealing at very high temperatures—up to 1200° C. (2200° F.)—and suggest a possible detrimental effect of sigma phase even in short annealing times.

5. A virtually complete survey by the notch-bend test of the commercial grades of stainless steel in the cold-drawn condition as received from the mill discloses that: (*a*) increasing carbon in the Class I steels markedly decreases bendability even when the steels are not in the hardened condition, (*b*) sulphur and selenium added to the free-machining grades greatly reduce bendability, (*c*) increasing chromium content in the ferrite of Class II steels greatly decreases bendability and (*d*) an important distinction exists between the titanium-stabilized Type 321 and the columbium-stabilized Type 347.

6. Further investigation of the contrast between Types 321 and 347 shows that: (*a*) Type 321 has an exceptionally high bendability whether cold drawn, annealed or stabilized, considerably exceeding not only that of Type 347, but of most other Class III steels, (*b*) stabilizing cold-drawn steels at 875° C. (1610° F.) improves both Types 321 and 347, also 310, but not 301, (*c*) annealing at 1040° C. (1905° F.) much improves all four of these grades, Type 321 showing no fracture whatsoever, (*d*) stabilizing the annealed steels for 1 hr. reduces the bendability of Types 347, 301 and 310, whereas Type 321 retains a full bend, (*e*) further stabilizing for 4 hr. causes Type 347 to attain a full bend and an equivalence with 321, although Types 301 and 310 show no change.

7. Fractographic study of the facets in Class II steels provides patterns by which the notch sensitivity of these ferritic steels can be understood, their fracture behavior determined, and the effect of increasing chromium content illustrated.

8. A special study of "475° embrittlement" in Type 446 discloses a sensitivity of the notch-bend test which allows detection of embrittlement after a $^1/_2$-hr. exposure at 475° C., whereas studies with unnotched specimens require many hours and days for the phenomenon to manifest.

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Aluminum-Magnesium Filler Metals for Welding High-Strength Aluminum Alloys

Welds made with the 8 to 10% aluminum-magnesium alloy rods had double the yield strengths of welds made with 43S filler metal using argon-shielded tungsten-arc welding and thick 61S, 24S and 75S aluminum alloy plates

by D. C. Martin and R. D. Williams

INTRODUCTION

THE weight of welded aluminum structures can often be reduced and economies obtained by using one of the high-strength aluminum alloys in place of alloys such as 2S and 3S. Alloys such as 61S, 24S and 75S can be fabricated by welding with 43S filler metal, and the yield strength of the joint will be double that of a similar joint in 2S or 3S aluminum. However, the designer who uses the high-strength alloys is forced to base his designs on the yield strength of the 43S weld metal which, while double the yield strength of 2S welds, is less than half that of the base plate.[1] This means that the design is not so efficient in its use of material as it could be. The way to get more efficient use of base material is to use a filler metal which produces a weld of higher yield strength than the filler metal presently used, and which has acceptable ductility.

In 1946, an investigation on the welding of thick, high-strength aluminum alloys was started at Battelle Memorial Institute for the Army Ordnance Corps. One of the objectives of this investigation was to develop high-strength filler metals. So far, about 25 filler-metal alloys have been evaluated. Some of them had high strengths in the as-welded condition, but low ductilities. Others had to be heat treated to develop high strengths, and some, although they produced high strength, relatively ductile all-weld-metal deposits, cracked so badly when deposited in high-strength base plate that they could not be used.

This paper describes the results of tests made with a series of aluminum-magnesium alloy filler metals. Certain alloys in this series produce welds that have yield strengths of 22,000 to 25,000 psi. (nearly double those of 43S welds), good tensile strengths (35,000 to 45,000 psi.) and adequate ductilities (6% in 2 in. or higher) in the as-welded condition.

The aluminum-magnesium alloys are reported to be susceptible to stress corrosion when the magnesium, content is over 5.25%. but when they can be protected this disadvantage is a minor one. Also, welds made with the aluminum-magnesium alloys contain a eutectic which melts at 840° F., and aluminum alloys welded with these filler metals cannot be given heat treatments requiring higher temperatures. This is not considered a handicap because the low strength of aluminum at solution-treating temperatures and the difficulty of getting a good quench make it unlikely that a large structure would be given a full heat treatment regardless of what filler alloy had been used to weld it.

The alloys investigated contained from 5 to 15% magnesium. At present, it appears that nothing would be gained by investigating alloys containing more than 15% magnesium. There is reason to believe, however, that alloys containing less than 5% magnesium might be useful for some applications; for example, welding 52S (2.5% magnesium) plate. These were not investigated in the work reported here. Examination of the information available on wrought and cast aluminum-magnesium alloys indicated that filler-metal alloys containing 5% or more magnesium would be most likely to produce welds with strengths appreciably higher than those of 43S welds.

MATERIALS USED

The $^3/_8$-in. thick base plates used in this investigation were the alloys known as 61S, 24S and 75S. The nominal compositions of these alloys are given in Table 1.

Table 1—Nominal Chemical Compositions of Aluminum Alloy Base Plate*

	Composition, %						
Alloy	*Cu*	*Mg*	*Mn*	*Si*	*Zn*	*Cr*	*Al*
24S	4.5	1.5	0.6	...	...	...	Rem.
61S	0.25	1.0	...	0.6	...	0.25	Rem.
75S	1.6	2.5	...	...	5.6	0.3	Rem.

* Data from "Alcoa Aluminum And Its Alloys," Aluminum Company of America.

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The 61S and 75S plates were used in the -T6 condition (solution treated and then artifically aged), while the 24S plate was used in the -T4 condition (solution treated and aged at room temperature).

A series of nine aluminum-magnesium filler metals was used. These contained from 5.25 to 15% magnesium. The nominal compositions of these alloys are given in Table 2. The filler metals were used as extruded $^5/_{16}$-in. rods.

Table 2—Nominal Compositions of Experimental Aluminum-Magnesium Alloy Filler Rods

Alloy designation*	Composition, %				
	Mg	Mn	Cr	B	Be
5†	5.25	0.1	0.1	...	...
7	7.0	0.2	...	...	...
8	8.0	...	...	...	...
9	9.0	0.2	...	...	...
10A‡	10.0	...	...	...	...
10B§	10.0	...	...	0.005	0.2
11	11.0	...	...	0.005	0.2
12	12.0	...	...	...	...
15	15.0	...	...	...	...

* These designations are used to indicate the nominal magnesium content of the filler-metal alloy.
† Alcoa 56S.
‡ Alcoa 220.
§ Acme Almag 55.

WELDING PROCEDURES

All welding was done with the inert-gas-shielded tungsten-arc process. An alternating welding current of 480 to 490 amp. was used at 28 to 32 arc v. The welding circuit contained storage batteries to balance the current. Superimposed high-frequency current was used for starting the arc. A $^5/_{16}$-in. diameter tungsten electrode was used. The shielding gas was argon, the flow rate 40 to 45 cu. ft. per hour. In all tests, a 300° F. preheat was used for the first pass, and the weld was allowed to cool to 300° F. between passes. All welding was done manually.

All-weld-metal test specimens were taken from two types of weld-metal deposits. One of these was made between air-cooled copper dams. These welds were made so that the strength properties of weld metal unaffected by dilution from the base plate could be studied. The other was made between alloy base plates, and, of course, the weld metal was diluted by the base plate.

Transverse tensile specimens were cut from double-vee joints.

WELDING CHARACTERISTICS OF ALUMINUM-MAGNESIUM ALLOYS

All of the aluminum-magnesium filler metals handled well. The molten metal flowed smoothly and produced welds of good appearance. During welding, the pool surface was partially covered with a gray skin, but this was not troublesome. The alloys had higher melting rates than filler metals such as 2S and 43S. This increased melting rate caused the operator to increase his welding speed in order to produce the proper size welds, but did not interfere with welding, once the operator had become accustomed to it. Penetration and fusion were the same as for 2S and 43S filler metals.

In general, the aluminum-magnesium alloys were not susceptible to hot cracking. The only cracks found were in welds in 24S plate made with the 5% magnesium alloy. In this case, the welds usually cracked just behind the weld pool and for the full length of the pass. According to Pumphrey and Jennings,[2] hot cracking of the type encountered in alloys such as the aluminum-magnesium series is caused by having a critical amount of eutectic present in the weld metal. The amount of cracking lessens rapidly as the amount of eutectic present decreases or increases from this critical amount. The critical amount of eutectic is present in the aluminum-magnesium alloys at 1% magnesium.[3] In view of this, it is believed that cracking should not be a problem in the higher magnesium alloys.

No gross porosity was found in any of the welds made with the aluminum-magnesium alloys. Other investigators[4-6] have reported trouble with porosity in welds in aluminum-magnesium alloys. However, this was in gas welds, and the porosity is reported to be caused by a magnesium water vapor reaction and consequent adsorption of hydrogen by the molten weld metal. When the argon-shielded tungsten-arc process is used and the filler wire is clean, very little water vapor is present in the arc area.

Some microporosity was found in the aluminum-magnesium welds. The amount was comparable to that found when other filler alloys, such as 43S, were used. It apparently had little effect on the strengths and ductilities of the welds.

RESULTS OF ALL-WELD-METAL TESTS

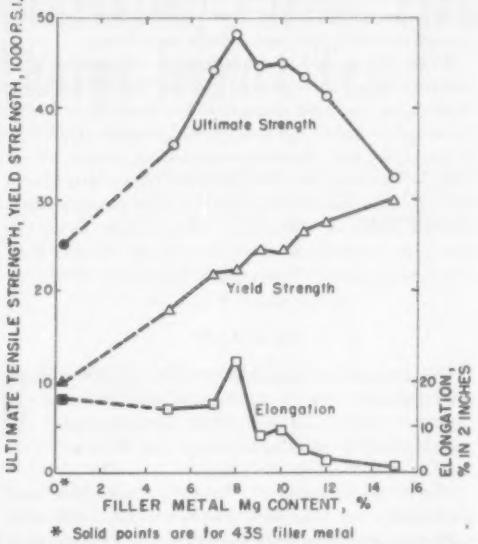
Tensile tests were made of all-weld-metal specimens cut from welds made between copper dams and 61S, 24S and 75S base plate. The results of these tests are given in Figs. 1 to 4.

The yield strengths of the weld metals increased as the magnesium content of the filler metal increased from 5.25 to 15%. For each filler-metal alloy the yield strength was about the same, regardless of whether it was deposited between copper dams or between the various alloy plates. This indicates that for the welds from which the data reported here were gotten, dilution from the base plate had no effect on yield strength.

The tensile strength and elongation increased as the magnesium content of the filler metal increased up to 10%. At higher magnesium contents there was some decrease in tensile strength, and a marked decrease in elongation. At 15% magnesium the elongation was only 1% in 2 in.

Dilution from the base plate appeared to have a significant effect on both the ultimate tensile strength and elongation. In general, each filler metal produced welds of the highest ultimate strength and elongation when deposited between copper dams where dilution did not occur.

Metallographic examination of welds made in 24S and 75S plates showed that they contained fine grain boundary constituents not present in the welds made between copper dams or 61S plates. It is believed that these constituents are responsible for the lower ductilities of welds made in 24S and 75S plates, and also for the lower tensile strengths of welds made in 75S plates. The constituents are probably a result of dilution of the weld by copper, zinc or copper and zinc from the base plate.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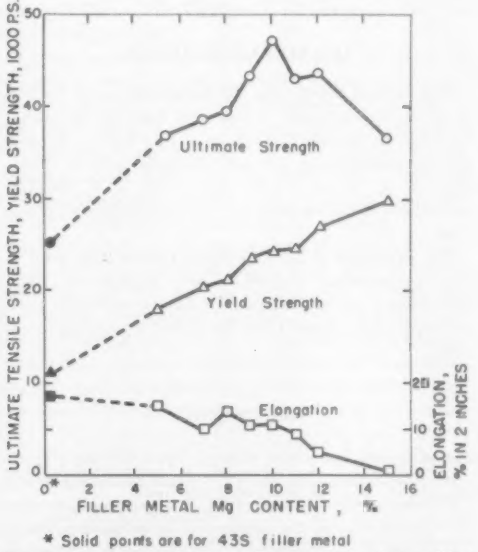
ELONGATION, % IN 2 INCHES
Ultimate Strength
Yield Strength
Elongation
FILLER METAL Mg CONTENT, %
* Solid points are for 43S filler metal

Fig. 1 Comparison of strength properties of as-welded all-weld-metal specimens cut from welds made between copper dams with the aluminum-magnesium alloys and 43S

In all figures the points at 10% Mg are the average of tests on 10A and 10B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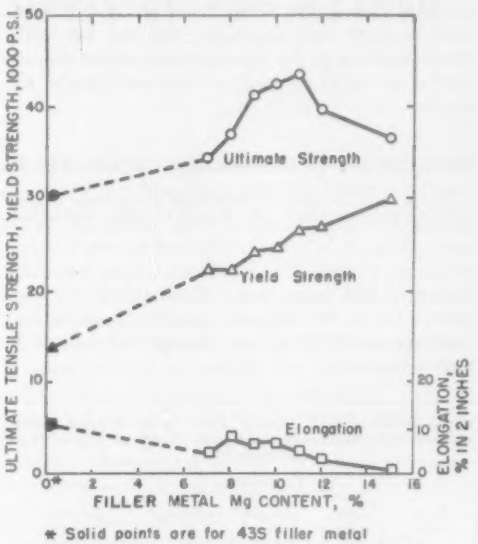
Ultimate Strength
Yield Strength
Elongation
FILLER METAL Mg CONTENT, %
* Solid points are for 43S filler metal

Fig. 2 Comparison of strength properties of as-welded all-weld-metal tensile specimens cut from welds made in 61S plate with the aluminum-magnesium alloys and 43S


ULTIMATE TENSILE STRENGTH, YIELD STRENGTH, 1000 P.S.I.
ELONGATION, % IN 2 INCHES
Ultimate Strength
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Elongation
FILLER METAL Mg CONTENT, %
* Solid points are for 43S filler metal

Fig. 3 Comparison of strength properties of as-welded all-weld-metal specimens cut from welds made in 24S base plate with the aluminum-magnesium alloys and 43S

Welds made with the 5.25% Mg alloy cracked

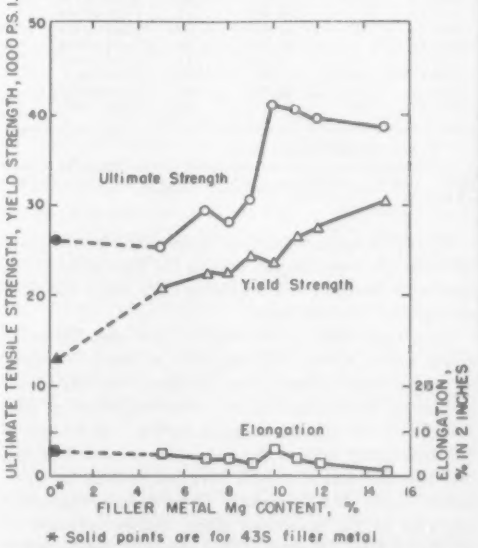
ULTIMATE TENSILE STRENGTH, YIELD STRENGTH, 1000 P.S.I.
ELONGATION, % IN 2 INCHES
Ultimate Strength
Yield Strength
Elongation
FILLER METAL Mg CONTENT, %
* Solid points are for 43S filler metal

Fig. 4 Comparison of strength properties of as-welded all-weld-metal specimens cut from welds made in 75S base plate with the aluminum-magnesium alloys and 43S

It can be seen in Figs. 1 to 4 that in all cases the aluminum-magnesium deposits containing from 5 to 10% magnesium have higher yield strengths than the 43S deposits. Even for the lowest magnesium alloy, the yield strength was 50% higher than for 43S, and for higher magnesium contents (8 to 10%) the yield strengths were almost double those of 43S. The ultimate strengths were also higher than for 43S welds. The elongations of the aluminum-magnesium deposits in all of the plates were only a little lower than for 43S deposits.

RESULTS OF TRANSVERSE TENSION TESTS

The results of tests of as-welded transverse tension specimens cut from joints in 61S-T6, 24S-T4 and 75S-T6 plates are given in Table 3. These tests were made on specimens welded with filler-metal alloys containing from 8 to 12% magnesium. These alloys were used because in the all-weld-metal tests they gave the best combinations of strength and ductility for welds in all three base plates.

Table 3—Results of Tensile Tests of As-Welded Transverse-Tensile Specimens Cut from Welds in Three Types of Base Plate*

Base plate	*Filler-metal alloy*	*Transverse tensile strength, psi.*	*Joint efficiency,† %*	*Location of fracture*
61S-T6	8	26,200	62	Heat-affected zone
61S-T6	9	26,000	62	Heat-affected zone
61S-T6	10B	27,300	65	Heat-affected zone
61S-T6	11	27,500	65	Heat-affected zone
61S-T6	12	26,600	63	Heat-affected zone
24S-T4	8	36,300	59	Weld metal
24S-T4	9	38,200	62	Weld metal
24S-T4	10B	35,000	56	Weld metal
24S-T4	11	33,300	54	Weld metal
24S-T4	12	34,000	55	Weld metal
75S-T6	8	33,700	44	Weld metal
75S-T6	9	33,900	44	Weld metal
75S-T6	10B	31,000	40	Fusion line
75S-T6	11	28,800	36	Weld metal
75S-T6	12	30,500	40	Fusion line

* All data average of two tests.
† Calculated from specified minimum tensile strengths of base plate: 61S-T6—42,000 psi.; 24S-T4—62,000 psi. and 75S-T6—77,000 psi.

All of the specimens taken from welds in 61S plate broke in the heat-affected zone in the base plate. The specimens broke at stresses only a little above the yield strength of the weld metal.

Specimens taken from welds in 24S and 75S plate failed either in the weld metal or at the fusion line. The appearance of the broken specimens indicated that, except for fusion-line failures, some reduction of area occurred in the weld metal before failure. In the case of the fusion-line failure, the reduction of area was less and the ultimate strengths were not so high as when failure occurred in the weld. There was no evidence of cracking in the specimens where failure occurred at the fusion line. It may be that this type of failure was caused by segregation in the weld, although, so far, no investigation of this has been made.

The results of the transverse tensile tests indicate that in 24S and 75S plates, the high yield strengths of welds made with aluminum-magnesium alloys can be utilized to good advantage. Designs using these base plates can be made on the basis of a 23,000 to 25,000 psi. yield strength rather than the 12,000 to 14,000 psi. yield strength of 43S. This should make possible savings in weight and cost in large structures.

When 61S is used, the weakened heat-affected zone prevents full utilization of the weld metal yield strength. In this case, the yield strength of the heat-affected zone is low and probably 43S welds would produce as efficient a design as the aluminum-magnesium alloys. It is possible, however, that welding techniques or procedures could be developed which would produce stronger heat-affected zones in 61S plate. If this were done, the aluminum-magnesium alloys would be better filler metals to use than 43S because of their higher strengths.

SUMMARY

The aluminum-magnesium filler-metal alloys have good usability with the inert-gas-shielded tungsten-arc process. They have good flow characteristics, and sound welds of good appearance can be made with them in 61S, 24S and 75S plate.

The alloys containing 5 to 10% magnesium (and particularly the 8 to 10% alloys) produce welds that have yield strengths twice as high as the yield strength of welds made with 43S, the filler-metal alloy commonly used today for welding thick sections of high-strength aluminum. The ductilities of welds made with the 5 to 10% magnesium alloys are only slightly lower than those of 43S welds.

ACKNOWLEDGMENTS

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The extrusion of the experimental filler rods used in this investigation required heavy equipment. The Aluminum Company of America did the extrusion work and we wish to thank them for their help and cooperation.

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Evaluating Carbon Plate Steels by the Keyhole Charpy Impact Test

Application of keyhole Charpy behavior in interpretation of the impact results of a number of carbon steels to show how transition temperature is affected by composition, deoxidation practice and plate thickness

by R. W. Vanderbeck

RECENTLY, Williams and Ellinger[1] demonstrated a correlation between the notch sensitivity of plates as evaluated by Charpy impact tests and the occurrence of brittle-type fractures in plates removed from ships that had failed in service. This is one of the few instances of this type in which a correlation between test results and service performance has been obtained. It was found that, at the temperature of ship failure, plates in which the fracture originated or through which the fracture passed absorbed, on the average, less than 10 ft.-lb. of energy. The plates in which fracture ended absorbed, on the average, somewhat more than 10 ft.-lb. at the temperature of ship failure. The V-notched specimen was used for these Charpy tests.

It has become the standard practice in the steel industry to use the keyhole-notch Charpy impact test when determining the notch toughness of carbon or alloy steel plate. Thus, the Steel Products Manuals on both carbon and alloy steel plates, published by the American Iron and Steel Institute, state that the Charpy type of test with the keyhole-notched specimen should be used when impact tests are specified.

A quite good correlation has been found to exist between the temperature at the 10 ft.-lb. level in the V-notch Charpy test and the temperature of transition from tough to brittle behavior in the keyhole-notch test.[2] There is some assurance, therefore, that Charpy impact data, obtained with either V-notched or keyhole-notched specimens, do correlate with behavior in service provided proper criteria are set up to judge the impact data. It is believed that the proper interpretation is obtained by selecting temperatures at low energy levels on the impact curves.[2] For the commonly used keyhole-notch Charpy test, this method of selection requires the determination of the rather abrupt transition from tough to brittle behavior. It is with this transition that the present paper is concerned.

The paper is divided into two parts. Part I describes the characteristics of keyhole Charpy behavior and shows how the data have been interpreted. Part II applies this interpretation to the impact results of a number of open-hearth carbon steels to show how the transition temperature is affected by composition, deoxidation practice and plate thickness.

Part I: Interpretation of Keyhole Charpy Data

CHARACTERISTICS OF KEYHOLE CHARPY RESULTS

All of the keyhole-notched Charpy specimens in these tests were made according to A.S.T.M. standards and were notched so that the axis of the notch was normal to the original plate surface. Longitudinal specimens (their length parallel to the rolling direction) were employed in all the cases to be described. Three impact tests were performed at each testing temperature, unless otherwise noted.

Two typical sets of notched-bar impact data for carbon-plate steel are shown in Fig. 1. Envelopes have been drawn around the plotted points to indicate more clearly the pattern of behavior. It will be noted that considerable scatter exists at certain temperatures. In one instance this scatter persists over a wide temperature range; in the other the range is much narrower. Above the scatter range the energy values are all relatively high, while below it they are uniformly low. Numerous other typical examples of this same type of behavior are shown in a recent article by Kahn and Imbembo.[3]

The range in which this scattering of energy values takes place is called the transition temperature range. Above the range the behavior will be considered uniformly tough and below the range, uniformly brittle. Within the range both tough and brittle types of behavior are encountered. The range therefore repre-

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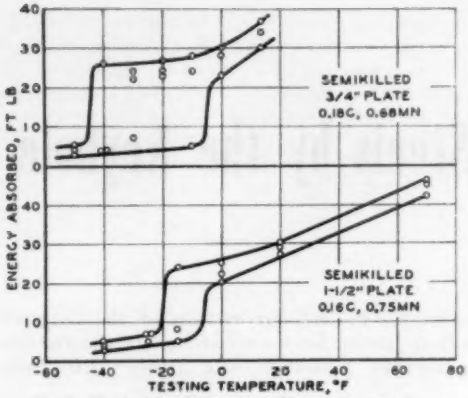

Fig. 1 Typical keyhole-notch Charpy impact data

sents the transition from tough to brittle behavior.

In this test the transition range is not the same, however, as the transition range from shear to cleavage failure. When the behavior is brittle or when less than approximately 10 ft.-lb. of energy is absorbed, the fracture appears to be 100% granular and the specimens show little or no deformation. Just above the transition range, where the behavior is tough, the fracture appearance is in most cases still predominantly granular and may show only 10 or 15% fibrous fracture. Most of this small amount of fibrous fracture occurs just below the notch, but a trace usually appears at the back and sides of the fractured surface also. The whole central portion of the fracture may therefore be granular. This same type of fracture is also obtained with specimens that behave in a tough manner within the transition range. But a completely fibrous fracture may not be obtained until the testing temperature is increased some 100° F. above the range in which the transition to brittle behavior takes place.

Osborn and co-workers,[4] experimenting with the Lehigh notched-bend test, the Penn State notched-bend test, and the Kahn tear test, have shown that test results on these specimens exhibit two energy transitions, one (at high energy levels) associated with the change in fracture appearance of the specimen as a whole, and the other (at low energy levels) associated with the change in fracture appearance of a small area just below the notch. The latter transition has been called by Stout and McGeady[5] the ductility transition; it represents the transition from relatively tough to brittle behavior. The transition from tough to brittle behavior that is observed for the keyhole-notched impact specimens may also be called a ductility transition, since the transition from tough to brittle behavior is associated with the change in fracture appearance of only a small area just below the notch.

BEHAVIOR IN THE TRANSITION RANGE

In the transition range where scatter occurs, it was noticed that in most instances the energy values were

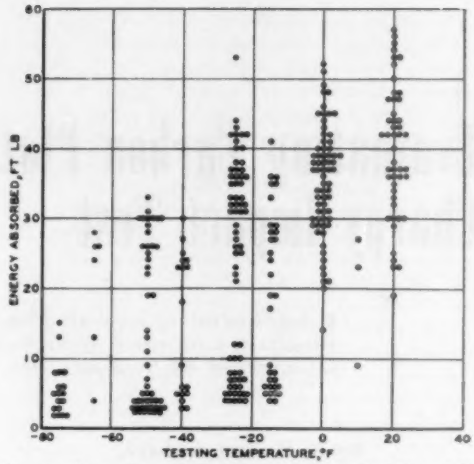

Fig. 2 Charpy impact results for four 0.16 C, 0.75 to 0.95 Mn, semikilled steels, showing the absence of values between 10 and 20 ft.-lb.

either relatively high or very low, with few intermediate values being obtained. Such behavior is observed in Fig. 1.

To illustrate further, four semikilled heats of steel containing about 0.16% C and from 0.75 to 0.95% Mn were tested in $^1/_2$-, 1- and $1^1/_2$-in. plate thicknesses at both the middle and at the bottom of the ingot positions in each thickness. Charpy impact tests were performed at various temperatures to determine transition ranges. All the sets of data, 24 in total, are plotted together in Fig. 2. It will be noted that for this type of steel only a small percentage of values lies between 10 and 20 ft.-lb. In the transition range, the values usually obtained are either above 20 ft.-lb. or below 10 ft.-lb., but seldom between these values.

This pattern of behavior is shown more clearly by a frequency distribution plot of the number of impact values occurring at each energy level. In Fig. 3 the data of Fig. 2 are analyzed in this manner. A moving average of three consecutive ft.-lb. values centered at

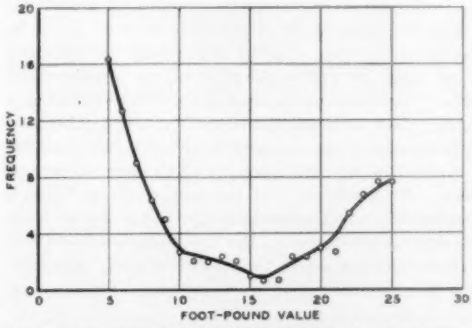

Fig. 3 Frequency distribution of Charpy ft.-lb. values at all testing temperatures for the semikilled steels of Fig. 2

the middle value has been used to smooth out the curve. The resulting curve verifies that few values occur between 10 and 20 ft.-lb. It also shows that a minimum point is obtained at 16 ft.-lb. This indicates that the energy is changing most rapidly with temperature at the 16 ft.-lb. level.

Frequency distribution curves for other steels are shown in Fig. 4. One curve was obtained from data on two silicon-aluminum-killed heats, one containing 0.16% C and 0.45% Mn, the other 0.16% C and 0.75% Mn, in $^1/_2$-, 1- and $1^1/_2$-in. plate thicknesses (see Table 1). Two ingot positions were tested as with the semikilled heats. The other two curves represent, respectively, semikilled and silicon-killed steels containing 0.20–0.25% C and 0.40–0.50% Mn. These were also tested in $^1/_2$-, 1- and $1^1/_2$-in. thicknesses (see Table 1). The minimum point in the curve for the 0.16% C, silicon-aluminum-killed steels occurs at about 16 ft.-lb. the same as for the 0.16% C, high-manganese, semikilled steels of Fig. 3. The minimum points for the steels containing about 0.23% C occur at a lower level, however—approximately 11 or 12 ft.-lb. For the latter steels, the range in which relatively few values are obtained has also been narrowed. The scatter of energy values is not so great as for the other steels.

The carbon content of a steel may be an important factor in determining the level at which the energy is changing most rapidly. In the lower-carbon steels this level apparently occurs at a higher ft.-lb. value (16 ft.-lb. for the 0.16% C steels). Deoxidation practice does not seem to have much effect, since both the silicon-aluminum-killed and the semikilled steels containing 0.16% C show a minimum in the distribution curve at the same ft.-lb. level (16 ft.-lb.). Similarly, the semikilled and silicon-killed steels that contain higher carbon both show a minimum at the same ft.-lb. level (approximately 11 ft.-lb.). Other factors also were examined, such as plate thickness and manganese content, but these did not appear to influence the position of the energy level where the fewest values occur.

WIDTH OF THE TRANSITION RANGE

The width of the transition range varies from one set of data to another and will usually be different for two determinations on the same steel. Some ranges are as wide as 50° F. or even wider. The scatter of impact values, which takes place in the transition temperature range, is believed to be caused by differences in specimen geometry, testing technique and steel constitution. Variations of this nature are not always avoidable, but some sort of control over these factors should help to narrow the temperature range of transition.

The width of the transition range that is obtained in testing depends not only on the factors mentioned above but also on the number of tests that are performed and their distribution temperature-wise. The range has no absolute limits and can be expressed only in statistical terms. Wittmann and Salitra[6] statistically investigated behavior in the transition range, testing 23 specimens at each of nine temperatures at intervals of 5° C. Unnotched specimens were used, and tests were conducted in a Charpy impact testing machine. The transition to brittle behavior was found to take place over a broad temperature range in which both tough and brittle behaviors were encountered. No intermediate impact values were obtained so the behavior was either tough or brittle. The probability of obtaining brittle behavior at any given temperature was found to be expressed by the integral of the normal Gaussian distribution curve, as shown in Fig. 5. This curve is also referred to as a cumulative frequency distribution curve. Thus it was found that the probability of tough or brittle behavior varied throughout the transition range in accordance with the law of cumulative Gaussian distribution.

It will readily be seen that the width of the transition range will depend upon the number of tests that are performed in the transition range. The more tests that are performed, the wider the range may be expected to be. For example, if three tests or even six tests were performed at a temperature corresponding to about 5% brittle expectancy on the probability curve

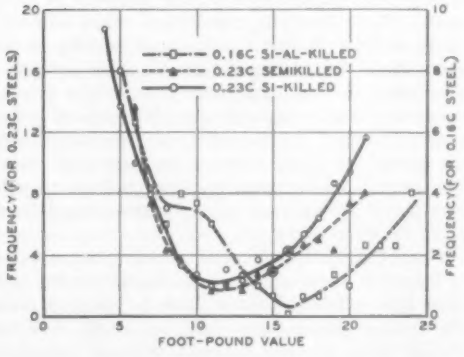

Fig. 4 Frequency distribution of Charpy ft.-lb. values at all testing temperatures for various steels

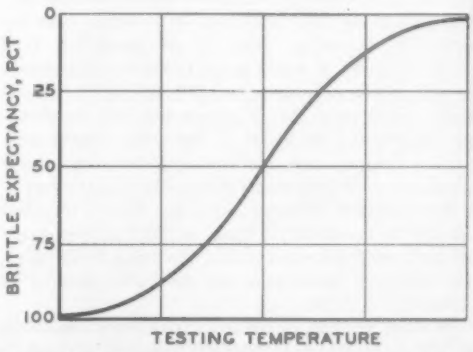

Fig. 5 Keyhole-notch Charpy behavior in the transition range

Table 1—Compositions of the Steels Investigated

Type steel	Heats studied in each thickness*	Positions studied per thickness per heat	Chemical composition C	Mn	P	S	Si	Acid sol. Al
Semikilled 0.45 Mn	3	3	0.20–0.26	0.40–0.50	0.008–0.020	0.020–0.035	0.030–0.050	...
Al-killed 0.45 Mn	4 in 3/4 in.	2						
Si-killed 0.45 Mn	3	3	0.21–0.26	0.40–0.55	0.008–0.020	0.025–0.035	0.008–0.018	0.030–0.103
Semikilled 0.75 Mn	3	3	0.20–0.25	0.40–0.50	0.015–0.020	0.026–0.036	0.18–0.22	...
	2†	2	0.16	0.75	0.015	0.031–0.035	0.030–0.048	0.003–0.007
	2 in 3/4 in.	2	0.17–0.19	0.70–0.77	0.010–0.014	0.018–0.031	0.034–0.050	...
	2 in 3/4 in.	1	0.16	0.65	0.011	0.028–0.034	0.046–0.07	...
Semikilled 0.95 Mn	2†	2	0.16–0.17	0.90–0.97	0.015	0.030–0.033	0.070	0.001–0.006
Si-Al-killed 0.45 Mn	1†	2	0.16	0.44	0.017	0.027	0.20	0.035
Si-Al-killed 0.75 Mn	1†	2	0.16	0.75	0.021	0.027	0.18	0.036
	1 in 3/4 in.	1	0.16	0.76	0.024	0.028	0.21	0.045
	1 in 1 1/2 in.	1	0.21	0.84	0.022	0.025	0.21	0.037

* In thicknesses of 1/2, 1 and 1 1/2 in., unless otherwise noted.
† The same heats were tested in the three different thicknesses.

of Fig. 5, it is likely that no brittle tests would be obtained. If 100 tests were run, however, it is most likely that the number of brittle specimens obtained would be five.

Carnegie-Illinois Steel Corp. is conducting a similar investigation using keyhole-notched Charpy specimens on aircraft quality, electric furnace 1019 steel, and the pattern of behavior that is being obtained is similar to that observed by Wittmann and Salitra. Although the aim was to obtain a steel with a relatively narrow transition temperature range, extensive testing has produced a range 55° F. wide. This work will be reported later in a separate paper.

DEFINING TRANSITION TEMPERATURE

In comparing steels, it is convenient to work with transition temperatures rather than transition temperature ranges. If it were feasible to determine statistically the temperature at which 50% of the specimens behaved in a tough manner and 50% in a brittle manner, this temperature might then logically be called the mean transition temperature. The extent of the scatter range might be expressed by another figure which would indicate how far above the transition 10% brittle behavior (or any other percentage) would be obtained and how far below the transition 10% tough behavior would be obtained. Thus, in the expression $-50 \pm 20°$ F., $-50°$ F. would be the transition temperature at 50% brittle expectancy, whereas 10% brittle expectancy would occur 20° F. above and 10% tough expectancy would occur 20° F. below this temperature. Such a determination, however, would require a larger number of tests than might practically be performed.

For practical purposes, it is convenient to select simply the middle of the range in which scatter occurs as the transition temperature. For example, in Fig. 1, the transition temperature for the 3/4-in. plate is, by definition, $-25°$ F.

It often happens, particularly with steels containing 0.25% or more carbon, that the change from tough to brittle behavior is more gradual, making it more difficult to select the scatter range and, hence, its middle. In such cases and, indeed, in all cases in this paper, the transition temperature has been selected at the middle of the scatter range at the energy level at which the energy absorbed is changing most rapidly with temperature.

Part II: Transition Temperatures of Production Heats

Transition temperatures have been determined for a number of basic open-hearth production heats in several hot-rolled plate thicknesses and with various carbon and manganese contents and different deoxidation practices. The compositions of the steels that have been investigated are listed in Table 1. The number of heats studied in each thickness is listed. The principal thicknesses studied were 1/2, 1 and 1 1/2 in. Those heats designated by the symbol "†" were investigated in all three thicknesses. In the other instances, different heats were used at each different thickness level. A few 3/4-in. plates of semikilled steel were also investigated and have been included in the comparison. For each thickness of each heat, transition temperatures were usually determined at two or three locations as indicated. These locations represented either different positions along the length of the ingot or different ingots. Since the location did not, in these instances, affect the transition temperature to any major extent, the various locations have not been differentiated in the graphs to follow. Impact specimens were taken from the quarter-line of the width of the plate in all cases. The location with respect to plate thickness varied. The tensile strengths of all the plates ranged from about 58,000 to 70,000 psi.

Figure 6 shows the individual transition temperatures of hot-rolled plates in various thicknesses for the first three types of steels listed in Table 1. In most cases the testing temperatures were sufficiently close to obtain fairly accurate determinations of transition temperature, but, in some cases, only rough estimates of the transition temperature could be made since no

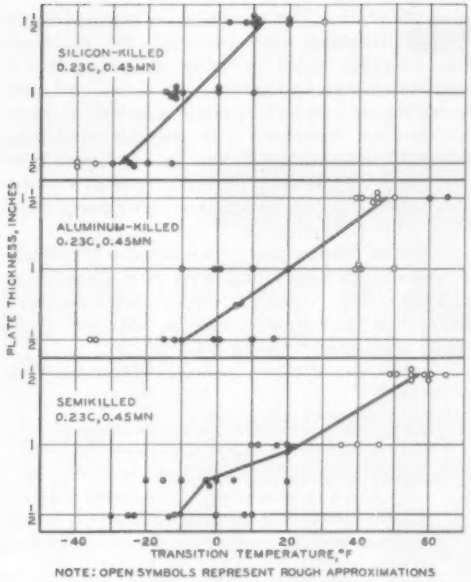

Fig. 6 Effect of plate thickness and deoxidation practice on the transition temperature

tests were conducted between 20 and 75° F. or below −25° F. The latter estimates are designated by the open symbols in Fig. 6.

It will be noted that, in general, the heavier plates have higher transition temperatures. This is a reflection of the higher finishing temperatures and slower cooling rates of the heavier plates. Both of these factors tend to produce a coarser ferrite grain size. Hodge, *et al.*,[7] have observed that the Charpy transition temperature is raised 30° F. in 0.02% C steel by an increase in ferrite grain size of one A.S.T.M. grain size number. Grain size estimates were made on the steels of the present experiment. It was noted that an increase in ferrite grain size of one A.S.T.M. grain size number was associated with an average increase of 20° F. for the silicon-killed steels and of 30° F. for the semikilled and the aluminum-killed heats.

The regular semikilled steels are typical of those that were produced during the war for hull plate on ships. The aluminum-killed heats were killed with aluminum only. The aluminum killing did not effect any significant improvement in transition temperature, for the results are similar to those obtained for the semikilled heats. A noticeable improvement in transition temperature was obtained with the silicon-killed heats.

Figure 7 shows the results obtained for the remaining steels in Table 1. It will be noted that the temperature

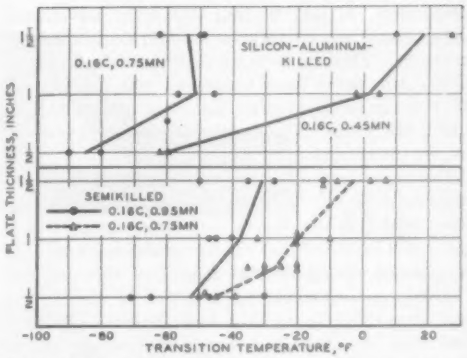

Fig. 7 Effect of plate thickness, composition and deoxidation practice on the transition temperature

scale of Fig. 7 differs from that used in Fig. 6. The semikilled 0.75% Mn heats are the type required by the new ABS specification for hull plate in thicknesses from 1/2 to 1 in., inclusive. These steels are decidedly better in notch toughness than the lower-manganese heats of Fig. 6. The 0.95% Mn heats appear to have somewhat lower transition temperatures than the heats with 0.75% Mn. It should be noted that these semikilled steels of lower carbon content contain higher manganese in order to maintain approximately the same strength level.

The silicon-aluminum-killed, fine-grained steel with 0.75% Mn has the lowest transition temperature of all the steels tested. The new ABS specification for hull steel calls for steel of this type in plate thicknesses over 1 in. With 0.45% Mn, however, this same type of steel in heavier thicknesses has a much higher transition. It is realized that additional data must be accumulated for the silicon-aluminum-killed steels before the above results can be considered representative.

The results of Figs. 6 and 7 are condensed in Fig. 8, which shows average transition temperatures for the various types of hot-rolled plate steel. The relative merits of each type of steel may be readily evaluated by

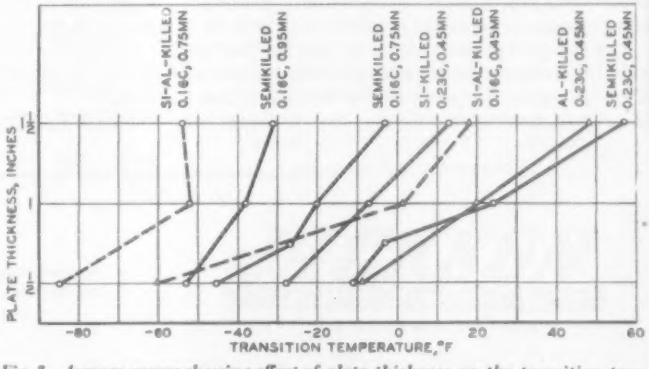

Fig. 8 Average curves showing effect of plate thickness on the transition temperatures of various carbon steels

comparison. It may be seen that lower carbon and higher manganese contents favor lower transition temperatures. Thus, of the semikilled steels, the 0.16% C, 0.75% Mn plates have transitions which are 35 to 60° F. lower, on the average, than those of the 0.23% C, 0.45% Mn plates. The greatest improvement is in the heavier thicknesses.

The importance of the deoxidation practice is quite apparent in Fig. 8. Killing with both silicon and aluminum produces the lowest transition temperatures, but it will be noted that the manganese must be high in order to obtain the full benefit of this practice. The lines representing the behavior of the silicon-aluminum-killed heats have been dashed to indicate that their positions are not well-established, because they are based upon relatively few data. Killing with aluminum alone produces no better results than semi-killing. It is important to note that these observations apply to plate steel in the as-rolled condition only.

SUMMARY AND CONCLUSIONS

Keyhole-notched Charpy impact tests were performed on $^1/_2$-, $^3/_4$-, 1- and $1^1/_2$-in. hot-rolled plates from production heats of carbon steel. Various deoxidation practices were employed, and the heats differed in carbon and manganese contents.

As the testing temperature was lowered, a sharp transition was obtained from tough (absorbing a minimum of about 20 ft.-lb.) to brittle (absorbing about 5 ft.-lb.) behavior. This transition took place over a range of temperatures. In this transition range, both relatively high and low impact values were obtained with few intermediate values. The absence of values at intermediate energy levels was clearly demonstrated by frequency distribution plots of the number of values occurring at different energy levels. A minimum point in the frequency curve is believed to indicate the energy level at which the energy is changing most rapidly with temperature.

The energy level where the fewest impact values occur seems to depend mainly upon the carbon content of the steel, and is higher for steels of lower carbon contents. Thus, for 0.23 and 0.16% carbon steels these energy levels are, respectively, about 11 and 16 ft.-lb.

The energy transition observed for the keyhole-notched Charpy specimens, as indicated by a scattering of energy values, is associated with the change from a fibrous to a granular fracture of a very small area just below the notch. This transition has been called the ductility transition and represents the transition from relatively tough to brittle behavior. But a completely fibrous fracture may not be obtained until the testing temperature is increased some 100° F. above the ductility transition. The ductility transition, therefore, is quite different from the well-known fracture transition (based on change in over-all fracture appearance) that has been obtained with many other types of notched specimens.

Transition temperatures were selected at the middle of the transition range at the energy level where fewest values occurred. Using this method of evaluation, a summary of the results for full-size, hot-rolled plates was obtained which is shown in Fig. 8.

It will be seen that low transition temperatures are favored by:

1. Deoxidation with both silicon and aluminum
2. Lower carbon and higher manganese contents
3. Lighter-gage plates. The lower transition temperature of thin plate is associated with its finer ferrite grain size, which is attributable to a lower finishing temperature and a faster cooling rate.

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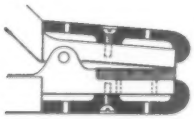

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